ARTERIAL STIFFNESS IN CHILDREN WITH AND WITHOUT DEVELOPMENTAL COORDINATION DISORDER

by

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Abstract

The purpose of this study was to determine whether children with potential developmental coordination disorder (p-DCD) demonstrate increased arterial stiffness and thickness compared to age and school matched controls (mean age 14.7 yrs). We also assessed whether these measures differed by sex. Compliance, distensibility, and intima-media thickness (IMT) were measured at the common carotid artery for 28 children with p-DCD and 47 controls. ECG-R-wave-toe pulse wave velocity (PWV) was also measured for 29 children with p-DCD and 45 controls. We found that compared to controls males with p-DCD had significantly higher PWV (3.8±0.2 vs. 4.1±0.3, p=0.001) and lower distensibility (0.82± 0.19 vs. 0.70± 0.17, p=0.034) while females showed no significant differences (p=0.523 and p=0.123 respectively). As a result, it is apparent that sex differences exist with respect to arterial health within this population and that children with p-DCD may be more likely to develop cardiovascular disease later in life.

Keywords: DCD, childhood disability, arterial stiffness, sex differences

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Abbreviations

ADHD	Attention deficit hyperactive disorder
ADL	Activities of daily living
ASA	American psychiatric association
BMI	Body mass index
BOTMP	Bruininks-Oseretsky test of motor proficiency
BP	Blood pressure
BRS	Baroreflex sensitivity
CCA	Common carotid artery
CSA	Cross sectional area
CVD	Cardiovascular disease
dCSA	Diastolic cross sectional area
DBP	Diastolic blood pressure
DCD	Developmental coordination disorder
DSM-IV	Diagnostic and statistical manual
HR	Heart rate
ICD-10	International classification of diseases
ICF	International classification of functioning, disability and health
IMT	Intima-media thickness
K-BIT	Kaufman brief intelligence test
M-ABC	Movement assessment battery for children
MAP	Mean Arterial Pressure
NO	Nitric oxide
PBF	Percent body fat
p-DCD	Potential developmental coordination disorder
P_d	Diastolic pressure
peak VO_2	Maximal aerobic fitness
PHAST	Physical health activity study team
PP	Pulse pressure
P_s	Systolic pressure
PWV	Pulse wave velocity
SBP	Systolic blood pressure
sCSA	Systolic cross sectional area
SD	Standard Deviation
sp-DCD	Suspect developmental coordination disorder
TD	Typically developing
TOMI	Test of motor impairment
WHO	World health organization

Chapter 1: Introduction

1.1 Preamble

Arterial stiffness refers to the arteries capacity to expand and contract during a cardiac cycle. Over time, arteries become more rigid due to changes in their structural composition and elastic properties. While this process is natural for an aging artery, it is accelerated by cardiovascular disease (CVD) and CVD risk factors such as hypertension, diabetes, obesity and hyperlipidemia (Riggio et al. 2010). In addition, arterial stiffness has been shown to negatively correlate with physical activity and fitness in both adults and in children (Seal et al. 2008; Madden et al. 2013; Reed et al. 2005). While CVD does not typically manifest itself in children, the presence of fatty streaks related to atherosclerosis may evolve as early as the 3rd year of life (Rubin & Reisner, 2013). As a result, children with CVD risk factors and those who are less physically active are at an increased risk of developing arterial stiffness.

Developmental coordination disorder (DCD) is considered a neurological disorder that affects approximately 1.8% of children worldwide and is more prevalent in boys than in girls (Lingam et al. 2009). Children with DCD exhibit poor motor skills and coordination, which adversely affects their daily activities both at home and at school (Miyahara & Mobs, 1995). In addition, children with DCD tend to be self-conscious of their poor motor skills and avoid structured physical activity compared to their typically developing peers (Cairney et al. 2010b). As a result, children with DCD have decreased physical activity levels and poor cardiorespiratory fitness. Furthermore, these children have less strength, higher percent body fat (PBF), and lower cardiovascular fitness with

a large proportion being overweight or obese (Cairney et al. 2005a; Schott et al. 2007). Consequently, children with DCD are at an increased risk of developing CVD risk factors. Therefore, it is hypothesized that these children will also be at an increased risk of altered arterial structure and function, as measured by arterial stiffness.

1.2 Rationale

There are currently no studies assessing arterial stiffness and thickness in children with DCD. Due to the high prevalence of obesity, low physical activity and fitness among children with DCD, and the link between obesity, hypertension, arterial stiffness and cardiovascular risk, the measurement of arterial stiffness in these children and how it differs from other children is especially important to study.

1.3 Objective

The primary purpose of this investigation was to determine whether children diagnosed with DCD demonstrate increased arterial stiffness and thickness as measured by pulse wave velocity (PWV), compliance, distensibility and intima-media thickness (IMT) of the common carotid artery (CCA) compared to age, sex and school matched controls. The secondary purpose was to examine whether arterial stiffness and thickness differ between sexes.

1.4 Hypothesis

We hypothesized that children with DCD would demonstrate increased arterial stiffness and thickness as reflected by an increase in PWV, and IMT, and a decrease in

compliance and distensibility compared to their age, sex and school matched controls. As well, arterial stiffness and thickness will be greater in males than in females.

Chapter 2: Review of the Literature

2.1.0 Arterial Health

The arterial system consists of a network of conduits that carry oxygenated blood throughout the body, supplying tissues with oxygen and nutrients. The most traditional model of the arterial system is called the lumped model or Windkessel model which relates the variation in blood pressure (BP) to the elasticity of large arteries like the aorta (Westerhof et al. 2009). In this model a portion of the blood ejected during systole remains stored in the aorta and is released during diastole allowing for continuous blood flow and maintenance of pressure during the cardiac cycle (Westerhof et al. 2009). This model is dependent on the structural components and mechanical properties of the arteries and abnormalities can affect the ability of the arteries to provide continuous flow of blood to the tissues (Rosset et al. 1996).

Traditionally, arteries have been divided into two categories: elastic and muscular. Elastic arteries include the aorta and the common carotid artery (CCA) while muscular arteries include the more peripheral arteries such as the brachial and femoral arteries. When the elastic arteries become stiff, blood flow becomes discontinuous and the large arteries store less blood during systole, thereby altering blood flow and pressure. These changes can lead to an increased load on the left ventricle and reduced coronary flow, and in turn increase the risk of cardiovascular events (Berne & Levy, 1997). The following sections will discuss vascular function and the indices used to measure arterial health.

2.1.1 Normal Vascular Function

As mentioned, the vascular system functions to maintain continuous flow of blood and oxygen through the systemic circulation. It accomplishes this through its viscoelastic properties, which allows large arteries, specifically the aorta to act as a buffer, sending only a portion of the stroke volume to the periphery during systole (Windkessel effect) (Salvi, 2012). This phenomenon can be seen in Figure 2.1.

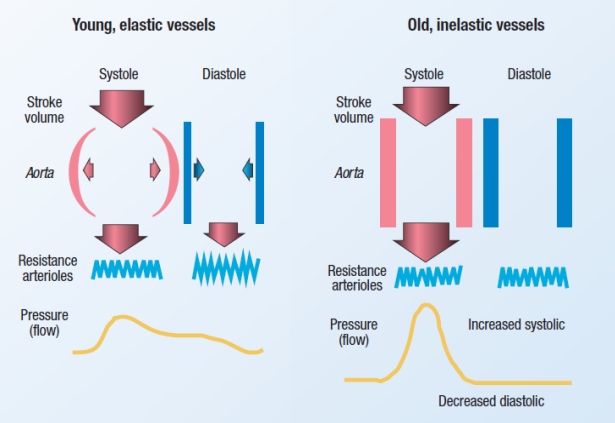

Figure 2.1 Aging and vascular function. The figure on the left illustrates the viscoelastic properties of young compliant arteries, while the figure on the right illustrates the change in vascular function with aging. (Taken from Izzo & Shykoff, 2001).

During the systolic phase, only a portion of stroke volume is ejected to the peripheral arteries, while the rest is stored in the aorta and other large elastic arteries (Izzo & Shykoff, 2001). Upon closure of the aortic valves and during diastole, the volume of blood that was retained during systole is propelled towards the periphery, thereby providing a continuous flow of blood throughout the circulation. Without the viscoelastic properties of the large arteries and the aorta, this continuous flow of blood would not be possible. This property of the arteries depends on the ratio between elastin and collagen within the arterial wall (Izzo & Shykoff, 2001).

Elastin is critical to the elasticity and resilience of the large arteries, especially within the aorta. In the vascular system its amorphous structure allows vessels to extend and recoil when needed to help maintain vessel homeostasis (Kothapalli & Ramamurthi, 2009). Elastin is an extremely durable, insoluble molecule that has a half-life of approximately 70 years in healthy tissue and generation of new elastin generally ceases after puberty, unless the fibres have been subjected to injury (Mithieux & Weiss, 2005). The correct assembly of elastic fibres is essential to its function and with ageing; degradation of this structure can lead to a reduction in extensibility and an increase in stiffness and disease. The aorta is comprised of 30-57% elastin while the major vessels are comprised of 28-32% elastin (Mithieux & Weiss, 2005). The ratio of elastic fibres within the vasculature tends to decrease with increasing distance from the heart since those vessels close to the heart are required to withstand greater changes in pressure without damaging the vessel (Safar et al. 2003).

Conversely, collagen fibres provide structural support and tensile strength to tissues and organs. Like, elastin, collagen is found within the extracellular matrix (ECM) of the media. There are 5 types of collagen found within the body and Types I and III are predominantly associated with the vasculature (Jugdutt, 2003). Type I collagen fibres are mainly associated with tensile strength, while Type III fibres are primarily associated with resilience. Approximately 85% of total collagen is Type I, while 11% is Type III (Jugdutt, 2003). Collagen fibres are able to provide strength and support through their α-chains that are intertwined to form a crystalline structure of triple helices (Muizneiks & Keeley, 2012). In addition, the extensibility of collagen fibres is far less than that of

elastin and has been documented at 13% as compared to 150% for elastin fibres (Muizneiks & Kelley, 2012).

The ratio of elastin and collagen varies among the different arteries in the arterial tree. For example, the dominant component within the aorta is elastin while the dominant component in peripheral arteries is collagen (Silver et al. 2001). When there are more elastin fibres than collagen, such as in the aorta, the elastic properties are high and better able to dampen the systolic wave produced by the left ventricle. In contrast, when there are a greater number of collagen fibres, there is increased stiffness and therefore less ability to dampen flow pulsation. A number of physiological and pathological conditions are able to alter the elastin/collagen ratio in the arteries and include aging, inflammation, hypertension and metabolic conditions (Salvi, 2012).

2.1.2 Arterial Stiffness

Arterial stiffness is a measure of the rigidity of the arterial wall and has been shown to be a surrogate marker of atherosclerosis and an important predictor of CVD in adults (Cecelja & Chowienczyk, 2012) and of CVD risk factors in children (Sakuragi et al. 2009). Characterizing arterial stiffness may be difficult due to the complexity of the arterial system. O'Rourke and Mancia (1999) state that when quantifying arterial stiffness it is important to note that not all arteries are homogenous and that elastic properties and pressures between and within arteries may alter stiffness.

Non-invasive measures of arterial stiffness fall within three groups: 1) relating the change in vessel size to distending pressure through measures of local arterial stiffness; 2) estimation of pulse wave velocity (PWV), the gold standard measure of

regional arterial stiffness; and 3) through pulse waveform analysis which looks at wave reflections to determine measures such as augmentation index (Sakuragi &Abhayaratna, 2010). No one measure has proved to be superior to the others and this thesis will focus on those most commonly reported, which include pulse pressure (PP), PWV, compliance and distensibility. In addition, intima-media thickness (IMT) has been shown to be a strong predictor of structural and functional changes in the vasculature (Robertson et al. 2012) and therefore will also be used to evaluate arterial health.

2.1.2.1 Pulse Pressure

Pulse pressure (PP) is the pressure difference between systolic and diastolic pressures and is currently considered a predictor of arterial stiffness. PP moves away from the heart at a finite speed and consists of compression waves that are produced by the force of each contraction (Izzo & Shykoff, 2001). When a compression wave encounters a zone of impedance, such as atherosclerotic plaques, bifurcation points or arterioles, it produces a reflected wave, which travels back to the heart. When large elastic arteries are compliant, the compression waves are responsible for systolic BP and the reflected waves which arrive from the periphery are responsible for diastolic BP (Izzo & Shykoff, 2001). When systolic pressure is high and diastolic pressure is low, as seen in those aged 55 and over, PP begins to increase (Franklin, 2004). This increase in PP is an indicator of central arterial stiffness and has become a dominant hemodynamic factor affecting BP in adults (Franklin, 2004).

It is mainly the role of the aorta and large arteries to minimize pulsatility – the pressure wave produced by the heart during left ventricular ejection. This is

accomplished through the cushioning capacity of the arteries. However, when this cushioning capacity is compromised due to arterial stiffening, PP increases. As arteries stiffen, the velocity of the compression wave increases causing the reflected waves to arrive from the periphery faster. This results in an increase in systolic pressure, as the reflected wave merges with the compression wave and a decrease in diastolic pressure. It can be seen in Figure 2.2 that as arteries stiffen, (as seen in the older adult), the reflected waves travel back to the heart faster, augmenting systolic pressure and decreasing diastolic pressure as compared to younger individuals. It is therefore apparent that the determinants of BP and PP are the cushioning capacity of the arteries and the timing and intensity of wave reflections (Safar et al. 2003).

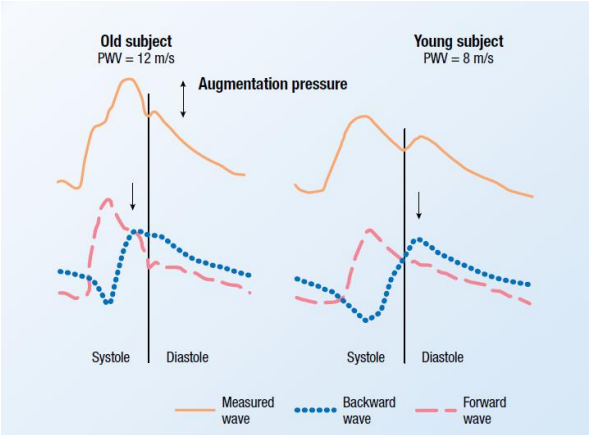

Figure 2.2 Central pressure contours and aging (Taken from Izzo & Shykoff, 2001).

2.1.2.2 Pulse Wave Velocity

Pulse wave velocity (PWV) has been established as a standard method for measuring arterial stiffness in both adults and children and is the speed at which a forward pressure wave is transmitted from the aorta through the vascular tree (Mackenzie et al. 2002). These pressure waves travel faster than the column of blood

and fluctuate between a minimum and a maximum to produce distinct waveforms (Izzo & Shykoff, 2001) which can then be used to determine the time it takes for the pressure wave to travel between two points in the vascular tree.

The equation for PWV is as follows: PWV = distance travelled (m)/time (s). Therefore, PWV involves measuring pulse waveforms from two sites within the vascular tree simultaneously or by gating separate recordings to a fixed point in the cardiac cycle (Mackenzie et al. 2002). Most often, the distance to each recording site is measured from the sternal notch and subtracted from one another in order to calculate the distance travelled by the waveform. As for the measurement of time, the most widely used method involves using the foot-to-foot method whereby, the time at the foot of the waveform at site 1 is subtracted from the time at the foot of the waveform at site 2. This method of measuring PWV will be used in this study.

Typically, young central arteries (less than 24 years of age) have a PWV of 5m/s (O'Rourke & Mancia, 1999). However, as an artery stiffens, pressure waves travel faster from the aorta and are reflected back at greater speeds (Schiffrin, 2004). As a result, PWV is indicative of arterial stiffness with lower values indicating a more elastic artery and higher values indicating a stiffer artery.

2.1.2.3 Compliance and Distensibility

Arterial compliance and distensibility are used to describe the elastic properties of the arterial wall and are evaluated using non-invasive high resolution ultrasound (Fernhall & Agiovlasitis, 2008). Distensibility is the ability of the artery to stretch under pressure and is defined as the relative change in area for a given pressure change:

$$((sCSA - dCSA) / dCSA) / (P_s - P_d)$$

where sCSA and dCSA are systolic and diastolic cross-sectional area and P_s and P_d are systolic and diastolic finger pulse pressures, respectively. Alternatively, compliance is the tendency of the vessel to resist recoil towards its original dimensions and is the absolute change in area for a given pressure change (Tziomalos et al. 2007):

$$(sCSA - dCSA) / (P_s - P_d)$$

Blood vessels with high compliance will experience only a small increase in systolic pressure with a large increase in blood volume. This is because the aorta and large arteries have a higher elastin to collagen ratio and are able to dampen the pressure through expanding and storing some of the extra blood volume to be released during diastole - Windkessel effect (Salvi, 2012). Conversely, arteries with a lower elastin to collagen ratio are not as able to dampen the additional pressure produced by the increased volume. As a result, the systolic pressure in these arteries is greatly increased, while the diastolic pressure is reduced. Hence, compliant arteries have narrow PPs, while stiff arteries have wider PPs. Furthermore, arterial compliance depends on the distending pressure in the vessel – therefore as arterial walls are stretched, the compliance and distensibility of the artery decreases (Izzo & Shykoff, 2001).

2.1.2.4 Intima Media Thickness

Intima-media thickness (IMT) is used as a marker for structural and functional vessel wall properties (Simons et al. 1999). It is measured using high resolution ultrasound from the leading edge of the lumen-intima interface to the media-adventitia

interface. It is often measured at the common carotid artery (CCA) since IMT at this site has been found to be related to adverse CV events (Fernhall & Agiovlasitis, 2008). In addition CCA IMT is suitable because of its large size, limited movement and superficial location making it relatively easy to image (Poredos, 2004). Furthermore, the far wall of the CCA is often used to measure IMT as visualization of the arterial layer interfaces within the near wall is often problematic (Bots et al. 2003).

In adults, increased CCA IMT is an indicator of early atherosclerosis and a strong predictor of future CV events (Lande et al. 2006). Increased IMT has been found to be associated with increased risk of myocardial infarction and stroke (Bots et al. 1997). Furthermore, studies have shown that CCA IMT is increased in several childhood diseases including hypertension (Litwin et al. 2004), diabetes (Krantz et al. 2004) and end-stage renal disease (Mitsnefes et al. 2004).

2.1.3 Arterial Stiffness and Cardiovascular Disease

Cardiovascular disease (CVD) is one of the leading causes of morbidity and mortality worldwide (Ton et al. 2012). The most common CVDs include atherosclerosis or a complication of atherosclerosis either stemming from or leading to hypertension (Damjanov, 2011). As such, it is important to understand the physiology of atherosclerosis and how it can affect vascular function. In addition, there are a number of CVD risk factors that have been implicated in the acceleration of arterial stiffness (Cecelja & Chowienczyk, 2012). These factors include, age, hypertension, hyperlipidemia, obesity, diabetes mellitus, and low physical fitness. Furthermore, a number of these risk factors can be easily controlled or modified to prevent the

progression of CVD. This thesis will focus on the CVD risk factors that are associated with arterial health in children; however, research on children in this area is not as extensive or conclusive as in adults.

2.1.3.1 Atherosclerosis

Atherosclerosis refers to systemic hardening of the arteries leading to a reduction of the arterial lumen as a result of lipid buildup in the walls of the arteries (Cecelja & Chowienczyk, 2012). Although it can manifest in any artery, it most often presents itself in the aorta, coronary arteries and cerebral arteries, including the CCAs (Solomon et al. 2001). It is believed that atherosclerosis results from endothelial cell injury as a result of increased shear stress (i.e. hypertension) or metabolic derangements (Damjanov, 2012). In the early stages of plaque development, small lipid deposits and fatty streaks form in the intima (Cecelja & Chowienczyk, 2012). These deposits may then progress into complex, heterogeneous plaque structures which are made up of a lipid core and a fibrous cap of connective tissue. Stiffness in large arteries, like the aorta, is increased in the presence of atherosclerosis and therefore arterial stiffness may be a useful marker when estimating the extent of plaque build-up in the large arteries (Cecelja & Chowienczyk, 2012).

Arterial stiffness and thickness measures such as compliance, distensibility, PWV and IMT are all affected by the presence of atherosclerotic plaque. Intima-media thickness (IMT) has been shown to reflect the first structural changes in the vascular wall and therefore can be used as a marker for the early stages of atherosclerosis (Nunez et al. 2010). Adult studies have shown that the presence of plaque in the carotid

arteries causes a reduction in compliance and distensibility (Lin et al. 1999) and an increase in PWV (Safar et al. 2003) and IMT (Bonithon-Kopp et al. 1996). While plaque structures may not be present in children, the manifestation of fatty streaks occurs during childhood and can be reversed if the lipids can be mobilized and removed from the vessel wall (Toth, 2009). In addition, children with endothelial dysfunction, who may be at risk for atherosclerosis, are at a greater risk for arterial stiffness and thickness compared to children without (Jarvisalo et al. 2004).

2.1.3.2. Age, Maturation and Sex

Increased central arterial stiffening is a hallmark of the ageing process (Zieman et al. 2005). Arterial stiffness increases left ventricular afterload and decreases coronary perfusion which can lead to CVD (DeLoach & Townsend, 2008). As a result, arterial stiffness is used as a marker for increased CVD risk. A complex interaction exists between the layers of the vasculature, hormones, and age during vascular stiffening (Zieman et al. 2005). Endothelial dysfunction affects the contractility of the vessels through disruptions in nitric oxide (NO) production and may also increase the permeability of the vessel to other toxic elements. In addition, arterial stiffness develops as a result of disruptions to the cellular and structural components of the vessel wall such as collagen and elastin. Stiffness does not affect all arteries in the same way and it tends to develop in the larger, more central arteries while not affecting the smaller more peripheral arteries (Zieman et al. 2005). However, McVeigh and colleagues (1999) found that compliance and therefore stiffness in small arteries can also be affected with aging.

In adults, it has been found that aging decreases compliance and distensibility and increases arterial stiffness (McVeigh et al. 1999; Arnett et al. 1994). There exists a complex balance between the production and degradation of the two scaffolding proteins, elastin and collagen, which allow the vessel wall to remain stable and compliant early in life (Zieman et al. 2005). As we age, the concentration of elastin within the vessel wall slowly degrades and the production of collagen increases, causing arteries to stiffen. The distal arteries are comprised of a greater collagen to elastin ratio than the more proximal ones. As a result, there is a stiffness gradient that develops between the proximal and distal arteries such as the carotid and radial arteries and in normal subjects of middle age this gradient is approximately 25% (Safar et al. 2003). This gradient is significantly reduced with age because of a reduction in proximal arterial compliance but not peripheral. Consequently, the central arteries become stiffer, while the components of the vessel wall in the peripheral arteries remains relatively stable. As such, the compliance, resilience and stability of the vessel wall is largely dependent on its two scaffolding proteins (Zieman et al. 2005).

The effects of aging on arterial stiffness and thickness are less well known in children and adolescents and studies report conflicting results. With respect to the effects of age on IMT, some studies have found an increase in CCA IMT with age in children (Jourdan et al. 2005; Hansen et al. 1995), while others have found little or no change in IMT during childhood (Sass et al. 1998). Differing results may be related to increases in arterial size and lumen diameter which occur naturally with growth (Fernhall & Agiovlasitis, 2008). The endothelium in arteries is able to detect shear stress

and induces luminal diameter modifications to maintain the stress within the artery. Vessel structure remodelling can also occur in the long term and significant relationships between wall shear stress and increased IMT have been found (Gnasso et al. 1996). While the relationship between IMT and age in childhood is unclear, it is important to control for age when examining IMT within this population.

Similarly, the effect of age and sex on arterial stiffness is controversial in children. Ahimastos and colleagues (2003) found that systemic arterial compliance and distensibility decreased throughout childhood. In addition, a review by Fernhall and Agiovlasitis (2008) suggest that CCA compliance decreases by 10-28% between 5 and 20 years of age. Conversely, Gardner and Parker (2010), found an increase in childhood compliance and distensibility with age until adulthood at which time, compliance decreased. While these studies report equivocal findings, all hypothesize that changes in compliance and distensibility are evident with age. Furthermore, differing results may be due to maturation and sex differences, which the majority of studies did not take into account.

As in adults, arterial tissue in children is thought to respond to sex hormones which are present in elevated amounts during puberty. These elevated levels of hormones may alter arterial properties and function (Aggoun et al. 2008). As such, the age trend for PWV in children throughout puberty is somewhat controversial. Several studies show that carotid PWV increases with age among children and throughout puberty and that these increases in PWV and arterial stiffness are similar in both males and females (Avilo et al. 1985; Cheung et al. 2002). In contrast, others suggest that

central and peripheral PWV may be altered with age and sex (Ahimastos et al. 2003; Reusz et al. 2010). In the study by Ahimastos and colleagues (2003), both central and peripheral PWV increased in males pre- to post-puberty. In females only central PWV decreased post-puberty, suggesting that there are inherent differences between males and females in arterial stiffness during maturation. It is therefore important to control for age, sex, and maturation when measuring PWV in children and adolescents.

2.1.3.3 Hypertension

In addition to age and maturation, hypertension in children (defined as a BP greater than the 95th percentile for their age, height and sex) has been associated with changes in arterial elasticity in adulthood. Elevated BP accelerates atherosclerosis and collagen synthesis which contribute to decreased arterial elasticity and in turn an increase in arterial stiffness (Juonala et al. 2005). A number of studies have looked at the effects of hypertension on arterial health indices in children. Several investigators have found that children with elevated BP and hypertension have increased IMT and arterial stiffness (Litwin et al. 2004; Lande et al. 2006; Sorof et al. 2003). Furthermore, follow-up studies have found that childhood hypertension is an in dependent predictor of increased PWV in adulthood (Davis et al. 2001; Li et al. 2004; Juonala et al. 2005).The structural wall changes that occur with elevated BP allow the pressure wave to travel faster throughout the arterial tree leading to an increase in central and peripheral PWV. A study by Li and colleagues (2004) looked at the effects of childhood hypertension on arterial stiffness in 835 black and white adults whose BP was measured during childhood. They found that high BP in childhood was an independent predictor of

increased ankle-brachial PWV in adulthood. A second follow-up study by Juonala and colleagues (2005) found similar results in carotid-femoral PWV. Finally, compliance and distensibility have been shown to be lower in children with hypertension (Litwin et al. 2004).

2.1.3.4 Obesity

Finally, obesity is associated with a number of negative health outcomes such as hypertension, hyperlipidemia, type 2 diabetes, stroke and coronary heart disease in adult populations (Dietz, 1998). Childhood obesity (BMI at the 95th percentile or greater) has been shown to be closely related to vascular endothelial dysfunction and is a risk factor for early atherosclerosis and is associated with decreased arterial elasticity (Jin et al. 2013). In addition, there is evidence that childhood obesity lays the metabolic foundation for CVD in adulthood (Srinivasan et al. 1996). Cardiovascular complications of obesity in children include dyslipidemia, hypertension and insulin resistance (Bridger, 2009). Children who are overweight or obese tend to have higher levels of triglycerides and low-density lipoproteins (LDL) and lower levels of high-density lipoproteins (HDL) leading to increased risk of atherosclerosis (Dietz, 1998). In addition, obese children are three times more likely to be hypertensive than non-obese children (Stabouli et al. 2005).

Several studies have shown the relationship between obesity and arterial health in children. Waist circumference, PBF and BMI have all been found to correlate positively with arterial stiffness and IMT (Tounian et al. 2001; Bohm et al. 2009; Jourdan et al. 2005). In addition, it is well documented that compliance and distensibility are

reduced in obese children. Tounian and colleagues (2001) compared CCA stiffness in 48 severely obese children with 27 controls. They found that children who were obese had significantly lower compliance and distensibility than healthy controls. There is however, still some debate as to whether IMT is related to obesity. In the same study, Tounian and colleagues (2001) found that IMT was not significantly different between severely obese children and healthy controls, while Stabouli and colleagues (2005) found that it was. Differences in the literature may arise due to the degree of obesity, and whether other CVD risk factors, such as hypertension, are present. Regardless, it is apparent that obesity is linked to arterial health and CVD risk in children and therefore must be considered during analysis.

2.1.4 Arterial Stiffness and Physical Activity and Fitness

Regular physical activity is associated with a number of benefits such as the preservation of health and function, increased longevity and decreased CVD risk through changes in BP, blood flow and oxygen consumption (Blair & Morris, 2009). Adult studies have shown that regular exercise can have positive effects on arterial health measures such as arterial stiffness, endothelial function and IMT (Seals et al. 2008; Madden et al. 2013). However, a limited number of studies have examined the relationship between arterial stiffness and physical activity in children.

Edwards and colleagues (2012) examined the effects of physical activity as measured by an accelerometer on arterial health measures in 156 adolescents and young adults. Arterial health measures included augmentation index, brachial artery distensibility and carotid-femoral PWV. Participants were assigned to a low, middle, or

high tertile of physical activity. Edwards and colleagues (2012) found that PWV was significantly lower in the high physical activity group, brachial artery distensibility was significantly higher in the high physical activity group and augmentation index was significantly higher in the low physical activity group suggesting that increased exercise has positive effects on arterial health.

Similarly, Pandit and colleagues (2014) examined the association of physical activity, and adiposity with arterial stiffness in Indian children and adolescents. Physical activity was divided into tertiles and assessed by using the Activity Questionnaire which has been previously validated (Barbosa et al. 2007). They found that increased adiposity and decreased physical activity levels were associated with increased arterial stiffness as measured by right CCA PWV, arterial compliance and elastic modulus. In addition, PWV was found to increase with adiposity for each tertile of physical activity.

Conversely, Schmitz and colleagues (2001) examined the relationship between CCA distensibility and self-reported sport, leisure and work related physical activity. The study consisted of 10,644 white and African-American men and women aged 45-64 years who were free of CVD. Interestingly, they did not find an association between physical activity and distensibility. These results, however, may be inaccurate as physical activity was self-reported during the first clinical visit and arterial distensibility was measured for 91% of subjects during the second clinical visit which was several years later.

In addition to physical activity, the effects of aerobic fitness on arterial stiffness in adults and children are important to examine. Aerobic fitness is a major determinant

of overall functional capacity and low levels have been identified as a risk factor for CVD in adults (Tanaka et al. 1998). Tanaka and colleagues (1998) examined the relationship between arterial health and aerobic fitness in adult women and found a significant inverse relationship between central arterial stiffness and maximal oxygen consumption. These results are also seen in men (Vaitkevicius et al. 1993).

The relationship between aerobic fitness and arterial stiffness in young adults and children is similar to adult studies; however, research in this area is limited. Boreham and colleagues (2004) examined the relationship between aerobic fitness, physical activity and arterial stiffness (measured as PWV from the aorta to the femoral artery and aorta to the toe) in 405 young adults (mean age, 22.6 years). Aerobic fitness was measured using a submaximal cycle ergometer and VO_{2max} was found to be significantly and inversely associated with PWV.

In addition, Reed et al. (2005) was the first group to examine the relationship between large and small artery compliance (as measured by applanation tonometry) and aerobic fitness in 99 children aged 9-11 years. They found that aerobic fitness, measured using Leger's 20m incremental shuttle run, was a strong predictor of large artery compliance and moderate predictor of small artery compliance. As a result, physical fitness is important to consider when examining arterial health measures in both adults and children.

Given the effects of CVD risk factors such as age and maturation, hypertension, obesity and decreased physical activity and fitness levels on arterial health, populations at increased risk for these factors are especially important to study. As a result, this

thesis will focus on a sub-population of children with developmental coordination disorder (DCD). Children with DCD are considered to have a coordination disorder that largely affects their ability/desire to perform physical activity and therefore greatly increases their risk of developing CVD later in life. This condition will be discussed in detail below.

2.2.0 Developmental Coordination Disorder

Developmental Coordination Disorder (DCD) is a term introduced by the American Psychiatric Association (ASA) in 1994 with the emergence of the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV). It was initially included in the DSM-IV because of its impact on everyday life during childhood and into adulthood and is now recognized as a distinct childhood disorder (American Psychiatric Association, 2013). Prior to its introduction, children with DCD were often incorrectly labeled as being clumsy or physically awkward. In addition, the terms *clumsy child syndrome, specific developmental disorder of motor function* and *childhood dyspraxia* are often equated with DCD, however, DCD is the preferred term (American Psychiatric Association, 2013; Henderson & Henderson, 2003). The following sections will describe the characteristics of DCD, how to diagnose it and its effects on everyday life.

2.2.1 Background of Developmental Coordination Disorder

The diagnosis of DCD is currently based on the criteria provided by the World Health Organizations (WHO) International Classification of Diseases (ICD-10) and by the DSM-V. The ICD-10 defines DCD as a serious impairment in the development of fine and

gross motor coordination that cannot be explained by neurological defects or intellectual impediments (WHO ICD-10, 2013). The diagnostic criteria of DCD provided by the DSM-V, is far more extensive. It encompasses the definition provided by the ICD-10 as well as motor coordination difficulties that may be present in both younger and older children, those that impair daily living, present themselves in early development and that cannot be explained by other conditions. The DSM-V criteria for the diagnosis of DCD are as follows:

A. The acquisition and execution of coordinated motor skills is substantially below that expected given the individual's chronological age and opportunity for skill learning and use. Difficulties are manifested as clumsiness (e.g. dropping or bumping into objects) as well as slowness and inaccuracy of performance of motor skills (e.g. catching an object, using scissors or cutlery, handwriting, riding a bike, or participating in sports).

B. The motor skills deficit in Criterion A significantly and persistently interferes with activities of daily living appropriate for chronological age (e.g. self-care and self-maintenance) and impacts academic/school productivity, prevocational and vocational activities, leisure and play.

C. Onset of symptoms is in the early developmental period.

D. The motor skills deficits are not better explained by intellectual disability (intellectual developmental disorder) or visual impairment and are not attributed to a neurological condition affecting movement (e.g. cerebral palsy, muscular dystrophy, degenerative disorder) (American Psychiatric Association, 2013).

Developmental coordination disorder is a motor coordination disorder that affects approximately 1.8% of children worldwide (Lingam et al. 2009). Depending on the severity of the condition, and how strictly the diagnostic criteria are applied, this value may range between 1.7 and 4.9% with milder forms and less stringent criteria

reporting higher rates (Cairney et al. 2011; Gillberg & Kadesjo, 2003). In addition, studies have shown that the prevalence of DCD appears to be higher in boys than in girls with ratios between 4:1 and 7:1 (Cairney et al. 2005b).

Children with DCD exhibit poor motor skills and coordination, which adversely affects their daily activities both at home and school (Miyahara & Mobs, 1995). As a result, children with DCD are often referred to as 'clumsy' and 'awkward' (Beutum et al. 2012). In addition, children with DCD tend to be self-conscious of their poor motor skills and may avoid structured physical activity and spend less time performing these activities compared to children without DCD (Cairney et al. 2010b). While DCD primarily affects motor control and performance, recent evidence suggests that it may also influence strength and have cardiovascular effects (Beutum et al. 2012; Chirico et al. 2011; Chirico et al. 2012). It has been demonstrated that children with DCD have less strength, higher body fat and lower cardiovascular fitness compared to their typically developing peers. In fact, an estimated 25 - 37% of children with DCD are obese or overweight, which may contribute to lower cardiovascular fitness (Cairney et al. 2005a; Schott et al. 2007).

It was once thought that only the most severely affected children with DCD would retain their coordination impairments into adulthood (Knuckey & Gubbay, 1983). However, evidence has shown that children that are mildly affected may also retain their motor coordination difficulties, which in turn can exclude them from important activities of daily living (Cantell et al. 1994). In addition, it has been shown that both children and adults may develop compensatory strategies when dealing with simple

tasks (Geuze & Borger, 1993; Shelley & Riester, 1972). As a result, it is important to age-adjust the difficulty of the task when testing adolescents and adults.

2.2.2 Diagnosing Developmental Coordination Disorder

DCD is recognized as a heterogeneous disorder because the symptoms and severity of the disorder may differ between children (Missiuna et al. 2006). As a result, there is currently no gold standard for the diagnosis of DCD and many factors may influence the choice of diagnostic procedures used. For example, factors include the reason for making the assessments, whether it is for screening purposes or as part of a research protocol; or the distinction between the product-oriented or process-oriented approaches (Geuze, 2007). In addition, the tests may be broken down into three groups, depending on the type of motor function with which they deal. The three groups are as follows:

1. motor coordination and behavioural tests
2. gestural and visuo-constructive praxis and;
3. movement perception tests mainly focusing on vision and kinaesthesis (Geuze, 2007)

Each group contains a number of different tests for researchers or clinicians to choose from. Within the first group assessing motor coordination and behaviour, the most frequently used tests are the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) and the Movement Assessment Battery for Children (M-ABC) (Geuze, 2007). These will be discussed in detail as they are relevant to this study.

The M-ABC was designed to assess motor difficulties in children between the ages of 4 and 12 years (Geuze, 2007). It is one of the most frequently used diagnostic

tools available for screening children with motor deficiencies and in the classification of DCD. As a result, it is becoming the examination of choice for both research and clinical diagnosis (Cairney et al. 2009). The M-ABC contains both quantitative and qualitative scoring components consisting of eight performance tasks and a checklist to assess the attitudes and feelings of the child towards motor tasks respectively. The performance tasks were originally modeled after Stott's (1972) Test of Motor Impairment (TOMI), which was later revised in 1984 by Henderson (Missiuna et al. 2006).

The M-ABC has been revised into the M-ABC2 which consists of 8 items that are subdivided into 3 groups; manual dexterity, ball skill and dynamic balance. Each task is scored from zero to 5 and summed to give a total impairment score out of 40, with high scores indicating greater impairment (Civetta & Hillier, 2008). The total impairment score can then be converted to age-related percentiles with scores below the 5^{th} percentile indicating severe motor impairments, while those between the 5^{th} and 15^{th} percentile indicate moderate impairment (Sugden, 2006). It has been shown that the performance of children with DCD may be affected by the environment and as such, these tasks were designed to test performance when the individual is stationary (manual dexterity), when the individual moves through an environment (obstacle avoidance) or when the environment is in motion (ball catching) (Cousins & Smyth, 2003). These tests therefore provide a good indication of a child's functional motor skills. Finally, the qualitative component of the M-ABC2 is a criterion-referenced checklist completed by a parent or guardian and provides information of the child's motor skills as assessed by the parent.

As for the BOTMP, it is used to assess fine and gross motor performance in children aged 4.5 to 14.5 years (Crawford et al. 2001). It was designed primarily to screen children with minor to moderate levels of motor impairment and requires a minimal level of verbal understanding and memory utilization, both of which make the test easy to administer (Geuze, 2007). The administration time of the full version is approximately 45-60 min and so a short version was created which uses fewer manipulations and requires only 15-20 min to administer. This short version (BOTMP-SF) has been used in a number of studies assessing motor proficiency (Cairney et al. 2009; Kambas et al. 2012; Tsiotra et al. 2009) and has been validated against the full version with correlations between 0.90 and 0.91 for children aged 8 to 14 years (Bruininks, 1978). In addition, it can be administered by trained research assistants as opposed to having a trained psychologist or occupational therapist administer the test, which may not always be feasible (Cairney et al. 2009).

While the BOTMP-SF has been reported as one of the most frequently used test, there is some concern with this test as the BOTMP-SF measures only the ability to perform the task and does not measure the quality of the movement (Missiuna et al. 2006). Some individuals may be able to perform the given task, but the speed with which they complete the task and the quality of the movement may not be functional (Missiuna & Pollock, 1995). In addition, studies have found inconsistencies between the validity of the BOTMP-SF against the M-ABC when identifying children with motor impairments (Spironello et al. 2010; Cairney et al. 2009; Dewey & Wilson, 2001). Despite these concerns the use of the BOTMP-SF appears to be a reasonable alternative to

identify motor impairments when assessment with the M-ABC is not available (Cairney et al. 2009).

2.2.3 Effects of Developmental Coordination Disorder

Children with DCD experience difficulties in motor coordination that may affect both fine and gross motor ability. As a result, this may have a negative impact on academic achievement, activities of daily living (ADL) and social and organized sport (Baeg et al. 2011).

Missiuna and colleagues (2008) conducted a study set out to describe the characteristics of a large sample of children with DCD aged 4 to 12 years (n=88). They found that the majority of children with DCD had problems with handwriting (n=76), cutting and crafts (n=74), task completion (n=67) and homework (n=65). As a result, difficulty with everyday tasks may lead to a higher risk of anxiety, depression and low self-esteem (Losse et al. 1991). In addition, attention deficit hyperactive disorder coexists in roughly half of all children diagnosed with DCD and therefore may influence their ability to focus on the task and further impact their academic performance (Baerg et al. 2011).

According to the International Classification of Functioning, Disability and Health (ICF), children with impairments in body structure and function experience considerable limitations in ADL (Wang et al. 2009; Summers et al. 2008). These activities include dressing, personal hygiene, eating habits, and participation in school and social activities (Figure 2.3). In addition, children with DCD tend to manifest motor coordination deficits in almost every motor domain, thereby further influencing their ability to complete ADL.

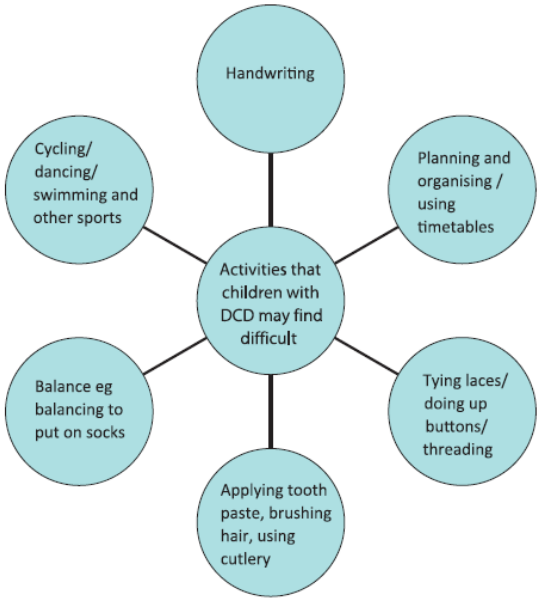

Figure 2.3 Activities of daily living that children with DCD may find difficult (Carslaw, 2011)

Summers and colleagues (2008) used a qualitative approach to explore the development of ADL in younger and older children with and without DCD from Australia and Canada. There were a total of 49 typically developing (TD) children and 38 DCD children from both countries. The developments of self-maintenance activities such as dressing and personal hygiene as well as eating behaviour were explored. Their results showed that very few younger children with DCD were able to dress independently compared to their TD peers. Children with DCD had problems with buttoning, fastenings, spatial orientation and poor balance. Similarly, only a few of the older children managed to attempt dressing at the level of the TD children. In addition, they found that both younger and older children with DCD most often required assistance with temperature control while bathing, while their TD peers were able to bathe mostly independently. Consequently, younger children with DCD were dependent upon their

parents for assistance with hair care, while both the older children with DCD and their TD peers had relatively few issues. Similarly, the younger children with DCD required parental assistance when brushing their teeth. As for eating habits, Summers and colleagues (2008) found that both the younger and older children with DCD had problems with coordination of utensils, inability to use a knife and general slowness while eating. These children were described as messy eaters and as having difficulty aligning themselves at the table when compared with their TD peers.

Lastly, the participation of children with DCD in social and organized sport have been found to be negatively affected due to their poor motor coordination and low self-efficacy (Cairney et al. 2005b). As a result, the willingness of children with DCD to participate in physical activity is reduced and these same children on average report a low level of enjoyment when engaging in free-play (Bouffard et al. 1996). This may cause serious health implications as physical fitness and cardiovascular health are both affected by physical activity.

2.2.3.1. Developmental Coordination Disorder and Physical Activity

Physical activity is defined as any bodily movement produced by the skeletal muscles that result in energy expenditure (Caspersen et al. 1985). As such, physical activity may be anything from ADL, such as household tasks to leisure-time activities such as sport and conditioning exercises. It has been reported that children with DCD are similar to their TD peers with respect to participation in individual activities such as swimming and gymnastics (Poulsen et al. 2007), however, studies have shown that children with DCD tend to participate less in group and free-play activities than their TD

peers (Cairney et al. 2005b; Bouffard et al. 1996). This may be attributed to the fact that they report lower self-efficacy with respect to their physical abilities (Cairney et al. 2005c). As a result, children with DCD show less preference for recreational, physical and skill-based activities (Engel-Yeger & Hanna Kasis, 2010).

Cairney and colleagues (2005b) investigated whether children with DCD report lower scores of self-efficacy when participating in organized and recreational free-play activities compared to those without DCD. In addition, they looked at whether sex influences this relationship. A total of 44 children met the requirements for probable DCD. Participants were between the ages of 9 and 14 years and were age, sex and school matched with controls. They found that children with DCD reported both lower self-efficacy and participated in free-play and organized activities less compared to their TD peers. As well, Cairney et al. (2005b) did not find a significant interaction between sex and DCD; however, the lowest levels of self-efficacy, participation in free play and organized sports were seen in girls, suggesting there may be a relationship.

Another study by Cairney and colleagues (2009) examined the relationship between p-DCD and sex over time. They found that the participation rates of children with p-DCD were lower with respect to free play. When they examined sex differences in this group over time, they found that males tend to increase the amount of active free play while females tend to decrease their participation. With respect to organized play, the activity deficit over time between sex remains constant in children with p-DCD (Cairney et al. 2009). This is consistent with the literature in that females become increasingly inactive through late childhood and adolescence (Kimm et al. 2005). As a

result, females with DCD may be especially at risk for inactivity compared to their male counterparts.

As indicated, children with motor impairments may be less likely to participate in organized sports and physical activity because their impairments make successful completion of many of the tasks difficult. As a result, children with DCD are at greater risk of developing secondary diseases, such as cardiovascular disease, due to their lack of participation in physical activity (Cermak & Larkin, 2002).

2.2.3.2. Developmental Coordination Disorder and Cardiovascular Health

Reduced physical activity can have significant long-term effects on health-related components of physical fitness. These components include aerobic and anaerobic endurance, flexibility, cardiorespiratory fitness and muscle strength. Hands and Larkin (2002) suggest that children mainly develop their physical fitness through activities that are both structured and unstructured. As a result, children with DCD are at a risk for low levels of physical fitness due to their reduced involvement in these types of activities. In addition, inactivity among children with DCD can lead to increased fat mass and it has been shown that children with DCD are more likely to be overweight and obese compared to their TD peers (Cairney et al. 2005a; Zhu et al. 2011; Hendrix et al. 2014).

Hands and Larkin (2006) compared 12 components of physical fitness in children aged 5 to 8 years with motor learning difficulties against age and sex matched controls. They administered a fitness assessment which consisted of 12 items including body composition, hip flexibility, muscle strength and cardiorespiratory fitness to name a few. The children with motor learning difficulties were found to have significantly higher

body mass index (BMI), which was attributed to body mass, and they performed significantly worse on various fitness components including the sit and reach test, sit-ups, standing broad jumps, 50m run and the shuttle run which is consistent with the literature (Haga, 2009). Deficiencies in certain components such as abdominal muscle strength, further contribute to poor coordination by compromising trunk stability and making gross motor skills more difficult to perform (Hands & Larkin, 2006). Longitudinal studies examining physical fitness in children with DCD had similar findings. Li and colleagues (2011) examined physical fitness over a three year period in Taiwanese children with DCD. They found that children with DCD demonstrated significant decreases in flexibility over time measured by the sit and reach test (year 1 - 28.2+/-6.8 cm; year 3 – 23.7+/-11.1cm), while their TD peers improved over time (year 1 – 28.2+/-7.8cm, year 3 – 31.4+/-7.7cm).

Cantell and colleagues (2008) examined the effects of low motor competence on physical fitness across different age groups; 8-9 year old children, 17-18 year old adolescents and 20-60 year old adults. They examined metabolic-related indices such blood lipid profile, caloric expenditure and BP, as well as fitness indices such as lung capacity, flexibility and muscular strength. A significant association between low motor competence and being overweight/obese was found. In addition, the low motor competence group tended to have lower levels of high-density lipoproteins than the high motor competence group, although no significant association was seen. Overall muscle strength, endurance and flexibility were also significantly lower for adults in the low motor competence group compared to adolescents within this group, suggesting

that continued hypo-activity may compromise muscular endurance and further contribute to poor coordination into adulthood.

Furthermore, Cantell et al. (2008) examined the effects of sex on metabolic indices such as BP, blood lipid profile and caloric expenditure. They found significant effects for sex and age on BP. Males in both the high and low motor competence groups had significantly higher SBP and DBP compared to the females, while children had significantly lower BP compared to adolescents and adults. Other studies have shown that low motor competence may also affect BP. Chirico and colleagues (2012) examined 33 children with p-DCD over three years and compared them to 53 age and school matched controls. They found that children with p-DCD had significantly higher SBP in year one compared to controls (111mmHg vs. 106mmHg respectively) while no differences were seen in years two or three. When this cohort was grouped into suspect DCD (sp-DCD), p-DCD and control groups, significantly higher DBP was seen between children with p-DCD and controls in year two (Coverdale et al. 2012).

One of the many consequences of reduced physical activity is low cardiorespiratory fitness, which is the ability of the circulatory and respiratory systems in the body to supply oxygen and fuel during physical activity. Faught and colleagues (2005) examined cardiorespiratory fitness in 571 children (mean age 11.5 ± 1.5 yrs) with DCD as estimated by the 20m shuttle run. They found that children with DCD reported significantly lower cardiorespiratory fitness compared to their TD peers and that physical activity is a significant mediator in this relationship (Faught et al. 2005). Similarly, Cairney et al. (2007) reported lower cardiorespiratory fitness (20m shuttle run)

in children with DCD across all ages (9-14 years). They found that children with DCD were more likely to have peak VO_{2max} scores below the 20^{th} percentile. These studies have been supported by Wu and colleagues (2010) who used peak VO_2, as estimated by the Bruce treadmill protocol to determine cardiorespiratory fitness. They found that cardiorespiratory fitness was significantly lower in children with DCD compared to their TD peers (39.7ml/kg/min vs. 47.6ml/kg/min respectively).

In addition to decreased physical fitness, reduced physical activity is an important risk factor for overweight and obesity (Hendrix et al. 2014). The WHO estimates that more than 40 million children are overweight with an estimated 30 million living in developing countries (WHO, 2013). In addition, 35% of adults aged 20 and over were overweight in 2008, and 11% were obese (WHO, 2013). Obesity is associated with a number of negative health outcomes for all ages, such as hypertension, hyperlipidemia, type 2 diabetes, stroke, coronary heart disease and osteoporosis in adult populations (Dietz, 1998). It has been hypothesized that DCD may be a risk factor for obesity resulting from decreased participation in physical activities. Many studies comparing the body composition of children with DCD to their TD peers have relied on BMI as the method for measuring obesity (Hands & Larkin, 2006; Cantell et al. 2008; Cairney et al. 2005a) however this method has its limitations. BMI is influenced by changes in maturation and it cannot provide a direct estimate of both the fat and lean mass components of body mass (Zhu et al. 2011). As such bioelectric impedance and whole body air displacement have been demonstrated to provide accurate measures of fat and lean mass in children and adults. Zhu and colleagues

(2011) used bioelectric impedance to determine overweight and obese status in children with and without DCD. A higher percentage of males with DCD were obese compared to their TD peers, while females with DCD had higher percentages of overweight and obesity than their peers. In addition, they found that obese boys and girls displayed worse motor coordination in both static and dynamic balance (Zhu et al. 2011).

Furthermore, reduced physical activity can have negative effects on cardiovascular health markers such as left ventricular structure and baroreflex sensitivity (BRS). To date, only one group has examined the effects of DCD on left ventricular structure. Chirico and colleagues (2011) measured the left ventricular mass (LVM) of 63 children with p-DCD and 63 healthy controls matched for age, sex and school. While they did not find significant differences in LVM between groups, they did find that left ventricular diastolic diameter, stroke volume and cardiac output were significantly higher in children with p-DCD compared to matched controls. These findings are consistent with the literature on obesity (Daniels et al. 1996), suggesting that children with p-DCD are at a greater risk of developing left ventricular hypertrophy, a precursor to CVD (Lorell & Carabello, 2000). Taking these findings one step further, Chirico and colleagues (2012) examined left ventricular structure longitudinally. The findings were similar to their pervious study with the addition that LVM, after a 3 year follow-up, was elevated in children with p-DCD and was significantly associated with cardiac output and fat mass. These findings suggest that overtime LVM could develop in children with p-DCD as increased left ventricular diameter is a precursor to LVM.

In addition, BRS, defined as the change in heart rate (HR) for a change in BP, has been found to be linked with cardiovascular morbidity and mortality (La Rovere et al. 1998). Although BRS varies with age and maturation, it is well known that in obese adults and adolescents, BRS is reduced (Lazarova et al. 2009). Coverdale and colleagues (2012) were the first to examine BRS in adolescents with p-DCD compared with their TD peers. They defined children at or below the 5th percentile on the M-ABC2 as having p-DCD and those between the 5th and 16th percentile as having sp-DCD. A total of 21 p-DCD (14 males, 7 females), 22 sp-DCD (12 males, 10 females) and 52 TD (29 males, 23 females) were analyzed. They found that BRS was significantly lower in the p-DCD group compared to their TD peers ($p=0.049$). This decrease was mainly attributed to a higher PBF in the p-DCD group. These results indicate that children with p-DCD may be at a greater risk of future cardiovascular events

2.3.0 Objective

There are currently no studies assessing arterial stiffness and thickness in children with DCD. Due to the high prevalence of obesity and consequently hypertension among children with DCD and the link between obesity, hypertension, arterial stiffness and cardiovascular risk, the measurement of arterial stiffness in these children and how it differs from other children is especially important to study. Therefore, the primary purpose of this investigation was to determine whether children diagnosed with DCD demonstrate increased arterial stiffness and thickness as measured by the indices of PWV, CCA compliance, distensibility and IMT compared to controls. The

secondary purpose was to examine whether arterial stiffness and thickness differ between sexes.

2.4.0 Hypothesis

We hypothesized that children with DCD would demonstrate greater arterial stiffness and thickness as reflected by an increase in PWV, PP and IMT and a decrease in compliance and distensibility compared to their age, sex and school matched controls. In addition, we hypothesized that arterial stiffness and thickness would be greater in males compared to females.

Chapter 3: Methods

3.1.0 Study Design

This study utilized data from a large cohort study called The Physical Health Activity Study Team (PHAST). Ethics approval was obtained from the District School Board of Niagara and from the Brock University Research Ethics Board (Appendix A). The PHAST study was conducted in two phases over a six year period. Phase I began in September of 2004 and children enrolled in Grade 4 were recruited from 75 of a possible 92 schools within the Niagara region. A total of 2378 children were contacted and received a form for informed consent (Appendix B). Informed consent was obtained from the parents of 2278 children (95.8%) at baseline. Baseline testing was completed in 2004 and data collection began in the spring of 2005 and continued bi-annually until the fall of 2007. Phase II began in September of 2007 and continued until June 2010. Phase II was a nested case-control design and consisted of annual lab-based and school-based health assessments for 63 children with potential DCD (p-DCD) and 63 age, sex and school matched controls. Data collected from lab-based assessments in phase II was used for this thesis.

3.2.0 Study Population

A total of 1785 students were asked if they would like to participate in the lab-based assessment of PHAST II, and 963 expressed an interest and agreed to be contacted by phone. There were 198 participants who were diagnosed with potential DCD (p-DCD) based on a score below the 10^{th} percentile using the BOTMP-SF prior to the beginning of PHAST II. The term potential DCD was used because no formal

diagnosis was established by a physician and criterion B of the DSM-IV was not directly assessed. Of the 198 participants with p-DCD, 63 agreed to participate in the study. Healthy controls were then age matched within six months, sex and school matched from consenting participants for a total of 126 participants at the beginning of PHAST II. Participants were school matched to control for socioeconomic status. After the first year of testing, 21 participants declined the invitation to come back for a second year, resulting in a sample size of 105. After the second year of testing, an additional 19 participants declined to come back for the final year of testing, resulting in a final sample size of 86 participants (33 p-DCD and 53 controls). Cross sectional analysis of year 3 data from PHAST II was used in this study.

3.3.0 Experimental Procedure

Participants were scheduled for an appointment in the Human Hemodynamic Laboratory at Brock University. Upon arrival, both participants and parents were reminded of the purpose of the study and consent forms were signed (Appendix B). Standing height, body mass and waist and hip circumference were measured and body composition was assessed using whole body air displacement plethysmography with the BOD POD (Life Measurement, Inc, Concord CA). Once participants completed the body composition measurements, they then entered the Human Hemodynamic Laboratory where cardiovascular measurements were taken.

Once in the lab, participants were asked to lay supine for a period of 15 minutes before data collection began to allow BP and HR to settle to resting levels. Following this rest period, three BP measurements were taken using a manual cuff

(sphygmomanometer) with each measure separated by one minute. The participants then underwent five minutes of beat-by-beat HR, BP and PWV data collection. Following baseline measures, right CCA ultrasound images were taken. While the images were taken, participants were asked not to swallow or move. Once data collection was complete, another three manual BP measurements were taken. All cardiovascular measures were completed by the same investigator for the duration of the study.

Upon completion of the cardiovascular assessments, participants were administered the M-ABC2 by a trained occupational therapist, followed by the completion of a peak oxygen uptake test. Finally, pubertal staging was completed 7-8 days following laboratory testing by a trained research assistant. The entire lab protocol took approximately 2 hours to complete and all information was recorded on the Advanced Health Information Sheet (Appendix C).

3.4.0 Experimental Measures

3.4.1 Body Composition

Measurements of body composition were performed in a private room with the parent(s) present. Standing height was measured in centimetres using a stadiometer (STAT7X, Ellard Instrumentation, Ltd., Monroe, WA, USA) and was recorded to the nearest 0.1cm. Body mass was measured in kilograms with a digital scale (BWB-800S, Tanita Corporation, Tokyo, Japan) and was recorded to the nearest 0.1kg. Participants were weighed wearing tight fitting clothing or swimsuits only. Body mass index (BMI) was calculated using body mass (kg) divided by height (m^2).

In addition, body composition was determined using air displacement plethysmography with the BOD POD. The BOD POD produces estimates of PBF, fat mass (FM) and lean muscle mass and has been shown to be both reliable and valid when measuring body composition in children and adults (Fields et al. 2002). Participants were asked to wear tight fitting clothing and were provided with a Lycra swim cap to reduce excess volume, which can alter body fat estimates (Higgins et al. 2001). When seated in the chamber, participants were reminded to remain still and to breathe normally. Two measurements, each 45s long were taken and averaged if they were within 150mL of one another. If the measurements were not within this range, a third measurement was performed and the two closest measures were used.

3.4.2 Blood Pressure and Heart Rate

Brachial BP was taken using a standard inflatable cuff and sphygmomanometer placed on the right arm while participants rested in the supine position. Three measures were taken and averaged to provide SBP and DBP values. In addition, continuous beat-by-beat non-invasive BP was collected from the left middle finger using photoplethysmography (Ohmeda 2300, Finapres Medical Systems, Arnhem, Netherlands). Because brachial and finger BP differ slightly, beat-by-beat BP was adjusted to the manual brachial BP to ensure accuracy (Imholz et al. 1990). Finally, HR was collected using a standard one-lead ECG.

3.4.3 Arterial Stiffness Measures

Central compliance and distensibility were measured for year 3 from images taken at the right CCA using non-invasive Echo-Doppler ultrasound (Vivid I, GE Medical Systems, Horton, Norway). Images were taken while participants were supine using an 8 MHz linear array transducer approximately 3 cm proximal to the carotid artery bifurcation. Three images consisting of five beat-by-beat diameter changes were taken for each subject using high resolution B-mode. To measure CCA compliance and distensibility, diameters corresponding to systole and diastole were measured for the two best images. For each five beat image sequence, the best three beats were chosen in terms of image quality and diameters were measured using computer automated edge detection software (EchoPac, GE Medical Systems, Netherlands) which automatically tracks the arterial wall and averages values from a specific location along the length of the artery. (Williamson et al. 2008). Pulsatile cross sectional area (CSA; πr^2, where r = diameter/2) and the corresponding finger obtained PPs were used in order to determine vessel compliance and distensibility using the following equations:

$$\text{Compliance} = (\text{sCSA} - \text{dCSA})/ (P_s - P_d)$$

and

$$\text{Distensibility} = ((\text{sCSA} - \text{dCSA}) /\text{dCSA})/ (P_s - P_d)$$

where sCSA and dCSA are systolic and diastolic cross-sectional areas and P_s and P_d are systolic and diastolic finger pulse pressures, respectively. PWV has also been shown to be an indicator of arterial stiffness and as a result was also measured in this study. PWV

is the speed with which the pulse wave travels along the length of the artery (Oliver & Webb, 2003) and as such is measured as distance over time. PWV is often measured as an indicator of arterial stiffness and can be calculated by the following formula (Salvi, 2012):

$$\text{PWV} = \frac{Distance}{\Delta T}$$

Distance (m) was measured from the sternal notch to the left middle toe. The time delay (s) between the onset of the ECG R-wave and the pulse waveform at the toe (Pulse Oximeter, PB-11341031, Nellcor, Boulder, CO) was used to calculate pulse transit time and ten consecutive beats were averaged for each subject.

Finally, intima-media thickness (IMT) was measured using computer automated edge detection software. The far wall of the left CCA was used to calculate IMT as visualization of the near wall is often problematic (Bots et al. 2003). Thickness was measured from the luminal surface of the intima to the media-adventitia interface. All measurements were taken at end-diastole to ensure the lowest possible tension on the arterial wall. Three beats were chosen for each subject from the two best images as determined by image quality. A total of six IMT measures were averaged for each subject.

3.4.4 Assessment of Motor Coordination

Motor coordination of all participants was assessed each year by a trained occupational therapist using the M-ABC2, which measures both fine and gross motor coordination (Appendix D). As children may perform better or worse depending on the

conditions or the day, an average of the 3 test scores was used to accurately identify children with motor impairments. Scores were converted into percentiles and those with averages below the 16th percentile were identified as p-DCD. As previously mentioned, potential cases of DCD were identified due to criterion B from the DSM-IV not being directly assessed. In addition, the Kaufman Brief Intelligence Test was administered by the occupational therapist to verify that the participants' intellectual ability was not below normal. Children with an estimated intelligence score below 70 are considered to be of below average intelligence (Vanny et al. 2009).

3.4.5 Aerobic Fitness

Peak aerobic power was measured through a maximal oxygen test using a programmed cycle ergometer (Excalibur Sport V2, Lode BV, Groningen, Netherlands). A continuous, incremental protocol was used. A mask and nose clips were used to collect metabolic gases which were analyzed using an Oxygen analyzer (Model S-3A, AIE Technologies, Pittsburgh, PA, USA). Participants were given the chance to familiarize themselves with the equipment. HR was monitored continuously during the assessment. Participants began cycling at 65 to 75 rpm with an initial power output of 20 Watts for the first three minutes. Every minute afterward, power output was increased by 20 Watts until the final stages where it was increased by 15 Watts until volitional fatigue. Two of the following three criteria were met in order to verify that peak aerobic power was achieved: HR was greater than 85% of the predicted maximum value (220-age), respiratory exchange ratio reached 1.00, and participants showed physical signs of effort and fatigue (facial reddening, difficulty maintaining power).

3.4.6 Maturation

Maturation was self-reported using secondary sex characteristics (Tanner, 1962) (Appendix E) during the home visits that occurred approximately one week after testing. Tanner staging uses five stages of development to assess maturation through pictures that represent the stages of primary and secondary sex characteristics (Tanner, 1962). Each participant was asked to select the picture that most resembled them. To avoid embarrassment, the participants completed the questionnaire independently in the privacy of their home 7 to 8 days following laboratory testing and placed it in an envelope to maintain confidentiality before handing it to the trained research assistant.

3.5.0 Statistical Analysis

Statistical analysis were carried out using SPSS software version 20.0 for Windows (SPSS Inc., Chicago, IL) and the level of significance was set at $p \leq 0.05$. Descriptive statistics for participants with p-DCD (average M-ABC2 over 3 years < 16^{th} percentile) and controls (average M-ABC2 over 3 years ≥ 16^{th} percentile) were examined for all variables using independent t-tests and chi-square tests where appropriate.

Non-parametric spearman correlations were performed as a number of the independent variables were not normally distributed even after log transformations. Correlations were performed to determine the association of possible predictors of arterial stiffness and thickness with arterial indices; PWV, compliance, distensibility and IMT. In addition, multivariate linear regressions were performed to confirm the sex effect of p-DCD on PWV and distensibility. Once confirmed, two multivariate linear regressions were performed in males to examine the effect of p-DCD on PWV and p-DCD

on distensibility, while controlling for HR, SBP, PBF, VO_{2FFM} and maturation. Results are expressed as mean ± standard deviation (SD).

Chapter 4: Results

4.1.0 Sample Characteristics

This study was part of a laboratory-based nested case control design examining the cardiovascular health of children with p-DCD. There were a total of 86 participants eligible for this study during year 3 of phase II testing. Of these, 33 were determined as p-DCD and 53 were TD controls. Table 4.1 shows demographic, anthropometric and cardiovascular characteristics for 22 p-DCD males and 30 male controls. Independent t-tests showed significant differences in demographic variables between groups with respect to M-ABC2 ($p<0.001$) where the p-DCD group had significantly lower percentiles compared to controls. Age, sex and K-BIT were not significantly different between groups. Significant anthropometric differences were seen between males with p-DCD and controls with respect to body mass, BMI, PBF and FM; all of which were higher in the p-DCD group ($p<0.01$). Finally, cardiovascular measures including HR ($p=0.012$) and peak VO_2 normalized to fat free mass (VO_{2FFM}, $p=0.008$) were significantly higher and lower, respectively in males with p-DCD compared to controls.

Table 4.1 Demographic and cardiovascular characteristics for male children with p-DCD (n=22) and controls (n=30).

	p-DCD	Control	p-value
Demography			
Age	14.8 ± 0.5	14.7 ± 0.4	0.357
M-ABC2 (percentile)	7.0 ± 4.6*	48.7 ± 14.8	0.000
K-BIT	94 ± 11.6	99 ± 10.8	0.146
Anthropometry			
Height (cm)	172.4 ± 6.5	172.8 ± 5.3	0.821
Body Mass (kg)	78.3 ± 24.4*	59.7 ± 8.2	0.002
BMI (kg/m^2)	26.2 ± 7.2*	20.1 ± 2.5	0.001
PBF	27.8 ± 11.5*	12.5 ± 6.8	0.000
FM (kg)	23.6 ± 15.5*	7.7 ± 5.1	0.000
FFM (kg)	54.7 ± 11.9	53.5 ± 9.0	0.685
Cardiovascular Variables			
SBP (mmHg)	113 ± 13	108 ± 11	0.149
DBP (mmHg)	64 ± 10	60 ± 11	0.192
MAP (mmHg)	80 ± 10	76 ± 10	0.129
HR (bpm)	74.9 ± 13.1*	66.7 ± 9.0	0.012
Peak VO_2 (L/min)	3.0 ± 0.7	3.3 ± 0.5	0.089
Peak VO_2 ($mL/kg_{FFM}/min$)	52.7 ± 7.7*	61.2 ± 10.3	0.008

Mean ± SD. Independent-samples T test *p ≤ 0.05. p-DCD = Potential Developmental Coordination Disorder, M-ABC2 = Movement Assessment Battery for Children 2nd edition, K-BIT = Kaufmann Brief Intelligence Test, BMI = Body Mass Index, PBF = Percent Body Fat, FM = Fat Mass, FFM = Fat Free Mass, SBP = Systolic Blood Pressure, DBP = Diastolic Blood Pressure, PP = Pulse pressure, HR = Heart Rate, bpm = beats per minute, MAP = Mean Arterial Pressure Peak VO_2 = peak aerobic fitness. SBP, DBP and HR are reported at rest.

Table 4.2 shows demographic, anthropometric and cardiovascular characteristics for 11 p-DCD females and 23 female controls. Independent t-tests showed significant differences in demographic variables between groups with respect to M-ABC2 ($p<0.001$) where the p-DCD group had significantly lower percentiles compared to controls. Age, sex and K-BIT were not significantly different between groups. Significant anthropometric differences were seen between females with p-DCD and controls with respect to PBF only ($p=0.028$), where females with p-DCD had higher PBF compared to

controls. Finally, cardiovascular measures including peak VO_2 (p=0.003) and peak VO_2 normalized to fat free mass (p=0.030) were significantly lower in females with p-DCD compared to controls.

Table 4.2 Demographic and cardiovascular characteristics for female children with p-DCD (n=11) and controls (n=23).

	p-DCD	Control	p-value
Demography			
Age	14.5 ± 0.4	14.6 ± 0.5	0.172
M-ABC2 (percentile)	7.5 ± 3.8*	48.0 ± 20.1	0.000
K-BIT	88 ± 16.2	96 ± 7.9	0.119
Anthropometry			
Height (cm)	161.6 ± 6.7	163.9 ± 5.7	0.303
Body Mass (kg)	63.8 ± 15.6	61.1 ± 11.9	0.584
BMI (kg/m^2)	24.4 ± 4.6	22.8 ± 4.2	0.331
PBF	32.1 ± 9.7*	25.3 ± 7.1	0.028
FM (kg)	21.5 ± 10.3	16.1 ± 7.4	0.086
FFM (kg)	42.3 ± 6.5	45.0 ± 6.2	0.237
Cardiovascular Variables			
SBP (mmHg)	105 ± 10	111 ± 10	0.097
DBP (mmHg)	64 ± 10	68 ± 12	0.223
MAP (mmHg)	77 ± 9	82 ± 10	0.142
HR (bpm)	73.6 ± 8.6	71.0 ± 9.0	0.431
Peak VO_2 (L/min)	2.0 ± 0.3*	2.4 ± 0.5	0.003
Peak VO_2 ($mL/kg_{FFM}/min$)	47.8 ± 7.1*	53.9 ± 7.4	0.030

Mean ± SD. Independent-samples T test *p ≤ 0.05. p-DCD = Potential Developmental Coordination Disorder, M-ABC2 = Movement Assessment Battery for Children 2nd edition, K-BIT = Kaufmann Brief Intelligence Test, BMI = Body Mass Index, PBF = Percent Body Fat, FM = Fat Mass, FFM = Fat Free Mass, SBP = Systolic Blood Pressure, DBP = Diastolic Blood Pressure, PP = Pulse pressure, HR = Heart Rate, bpm = beats per minute, MAP = Mean Arterial Pressure Peak VO_2 = peak aerobic fitness. SBP, DBP, and HR are reported at rest.

The distribution of children within the different stages of sexual maturation can be seen in Table 4.3. Maturational stage did not differ between groups with respect to pubic hair development in males or females. It can be seen that the majority of children

(males and females) in both the p-DCD and control groups lie within the 4th and 5th Tanner stages of development.

Table 4.3 Distribution of children with p-DCD and controls across Tanner stages of pubic hair development.

	Males		Females	
Tanner Stage	**p-DCD**	**Control**	**p-DCD**	**Control**
1	0 (0)	0 (0)	0 (0)	1 (4)
2	2 (9)	0 (0)	0 (0)	2 (9)
3	1 (5)	2 (7)	2 (18)	6 (26)
4	5 (23)	7 (26)	6 (55)	12 (52)
5	9 (41)	12 (44)	3 (27)	2 (9)
6	5 (23)	6 (22)	-	-

Frequency (percent). Missing information for 3 male controls. p-DCD = Potential Developmental Coordination Disorder

Spearman correlations were analyzed for measures of body size and cardiovascular characteristics (BP, HR, MAP and aerobic fitness) as they are known to influence arterial stiffness and thickness. The results of Spearman correlations are presented in Table 4.4. Due to missing data, sample size varied. Correlations involving compliance, distensibility, PP and IMT had a sample size of 75 while those involving PWV had a sample size of 74. All other correlations contained the full sample size of 86 participants. PWV had weak positive correlations with SBP ($p=0.006$), HR ($p=0.024$) and PP ($p=0.044$) and weak negative correlations with distensibility ($p=0.007$). Distensibility had weak negative correlations with PBF ($p=0.008$) and MAP ($p=0.021$), moderate negative correlations with SBP ($p=0.001$), and PP ($p<0.001$) and a strong positive correlation with compliance ($p<0.001$). Compliance had a weak negative correlation with SBP ($p=0.017$). In addition, PBF had a weak positive correlation with HR ($p=0.027$),

DBP had a weak positive correlation with HR (p=0.013) and finally HR had a weak negative correlation with VO_{2FFM} (p=0.008). Variables with significant correlations to measures of arterial stiffness and thickness were controlled for in the covariate adjusted multivariate linear regression models below.

Table 4.4 Spearman correlation coefficients (r) between dependent and independent variables

	PBF	SBP	DBP	MAP	HR	VO_{2FFM}	PWV	DIST
PBF	1.00							
SBP	.069	1.00						
DBP	-.014	.578**	1.00					
MAP	.053	.766**	.840**	1.00				
HR	.243*	.185	.272*	.184	1.00			
VO_{2FFM}	-.261*	.159	-.019	.057	-.287**	1.00		
PWV	.179	.316**	.031	.020	.262*	-.049	1.00	
DIST	-.302**	-.363**	-.068	-.265*	-.184	.126	-.330**	1.00
COMP	-.094	-.274*	-.052	-.199	-.100	.155	-.200	.716**
PP	.134	.341**	-.329**	-.067	-.137	.290*	.251*	-.451**
IMT	-.076	.005	-.006	-.001	-.033	.054	-.129	.034

* Significance at level of p<0.05.

** Significance at level of p<0.001

PBF = Percent Body Fat, SBP = Systolic Blood Pressure, DBP = Diastolic Blood Pressure, MAP = Mean Arterial Pressure, HR = Heart Rate, VO_{2FFM} = Maximal Aerobic Fitness normalized to Fat Free Mass, PWV = Pulse Wave Velocity, DIST = Distensibility, COMP = Compliance, PP = Pulse Pressure, IMT = Intima-Media Thickness. Correlations involving compliance, distensibility, PP and IMT had a sample size of 75 while those involving PWV had a sample size of 74. All other correlations contained the full sample size of 86 participants.

4.2.0 Arterial Characteristics

Characteristics of arterial structure and function are shown in Table 4.5 and are presented separately by both group (DCD versus control) and sex. A total of 18 p-DCD males and 27 male controls were analyzed for compliance, distensibility, and IMT. Of the original 22 p-DCD males, 1 had images that were technically difficult to determine accurate arterial interfaces and 3 had images that were unable to transfer into the EchoPac for analysis and therefore were excluded. Of the original 30 male controls, 3

had images that were unable to transfer into the EchoPac for analysis and therefore were also excluded from analysis.

Pulse wave velocity was also compared between groups in males and a total of 20 p-DCD and 26 controls were analyzed for this measure. Of the original 22 p-DCD males, 1 was missing an ECG recording and 1 did not have a measured distance from the sternal notch to the toe and therefore were excluded from analysis. Of the 30 controls, 1 was missing ECG, 1 was missing beat-by-beat pulse waves at the toe, and 2 were missing chart files.

Independent t-tests showed significantly lower distensibility ($p=0.034$) and significantly higher diastolic diameter ($p=0.026$) and PWV ($p=0.001$) in males with p-DCD compared to controls. No significant differences were seen between p-DCD and controls for the measures of arterial compliance, and IMT.

Characteristics of female arterial structure and function are also shown in Table 4.4. A total of 10 p-DCD females and 20 female controls were analyzed for compliance, distensibility, and IMT. Of the original 11 p-DCD females, 1 had images that were technically difficult to determine accurate arterial interfaces and was therefore excluded. Of the original 23 controls, 3 had images that were unable to transfer into the EchoPac for analysis and therefore were also excluded from analysis.

Pulse wave velocity was also compared between groups in females and a total of 9 p-DCD and 19 controls were analyzed for this measure. Of the original 11 p-DCD females, 2 were missing ECG recordings and therefore were excluded from analysis. Of the 23 controls, 1 was missing ECG, 1 was missing beat-by-beat pulse waves at the toe, 1

was missing a measured distance from the sternal notch to the toe and 1 was missing their chart file.

Independent t-tests showed no significant differences between p-DCD females and female controls for the measures of arterial compliance, distensibility, PWV, and IMT; however this may be a problem of power as there were only 10 females with p-DCD.

Compliance and IMT were not normally distributed therefore log transformations were performed on these variables to reduce the skew. Independent t-tests were performed on compliance and IMT using the log transformed data. P-values obtained using the transformed data were similar to those obtained using non-transformed data and therefore the p-values represented in table 4.5 are the non-transformed values.

Table 4.5 Arterial health measures in children with p-DCD and controls by sex

	p-DCD	Control	p-value
MALES	n=18	n=27	
Arterial Diameters			
Systolic (mm)	6.55 ± 0.41	6.29 ± 0.57	0.103
Diastolic (mm)	5.64 ± 0.45*	5.31 ± 0.48	0.026
Difference (mm)	0.87 ± 0.22	0.97 ± 0.23	0.171
Arterial Stiffness			
PP (mmHg)	52.2 ± 13.5	50.5 ± 9.2	0.619
PWV (m/s)	4.1 ± 0.3* (n = 20)	3.8 ±0.2 (n = 26)	0.001
Compliance (mm^2/mmHg)	0.17 ± 0.03	0.18 ± 0.05	0.506
Distensibility ($mmHg^{-2}$)	0.70 ± 0.17*	0.82 ± 0.19	0.034
Arterial Thickness			
IMT (mm)	0.39 ± 0.04	0.40 ± 0.05	0.483
FEMALES			
Arterial Diameters	n=10	n=20	
Systolic (mm)	6.06 ± 0.50	6.15 ± 0.47	0.608
Diastolic (mm)	5.23 ± 0.40	5.36 ± 0.40	0.379
Difference (mm)	0.86 ± 0.18	0.77 ± 0.17	0.260
Arterial Stiffness			
PP (mmHg)	44.2 ± 7.2	46.3 ± 7.3	0.464
PWV (m/s)	3.8 ± 0.4 (n = 9)	3.8 ±0.3 (n = 19)	0.523
Compliance (mm^2/mmHg)	0.17 ± 0.05	0.16 ± 0.05	0.492
Distensibility ($mmHg^{-2}$)	0.79 ± 0.14	0.70 ± 0.15	0.123
Arterial Thickness IMT (mm)	0.39 ± 0.03	0.39 ± 0.05	0.981

Independent-samples T test *p ≤ 0.05.p-DCD = Potential Developmental Coordination Disorder, PP = Pulse Pressure, PWV = Pulse Wave Velocity, IMT = Intima-Media Thickness.

4.3.0 Multivariate Linear Regressions of p-DCD on Pulse Wave Velocity and Distensibility

Multivariate linear regressions were used to confirm the sex differences seen in PWV and distensibility. PWV and distensibility were analyzed based on two models; 1)

effect of p-DCD, 2) model 1 plus sex and sex/p-DCD interaction. Significance was set at $p<0.05$.

In the first model (Table 4.5), examining p-DCD and PWV, the main effect of p-DCD was positive and significant (p=0.016), accounting for 6.5% of the variability in PWV ($R^2_{adjusted}$ = 0.065). When sex and the sex-p-DCD interaction term were entered into model 2, the interaction term was significant (p=0.010). As a result, the effect of p-DCD on PWV is different for males and females. To better understand this difference, we graphed the association between sex, p-DCD and PWV using the regression equation from Table 4.6. It can be seen in Figure 4.1 that male and female controls have similar PWV while males with p-DCD have higher PWV and females with p-DCD have lower PWV compared with controls.

In the first model examining p-DCD and distensibility, the main effect of p-DCD was not significant (p=0.389). However, when sex and the sex-p-DCD interaction were added into model 2, the interaction term was significant (p=0.013). As a result, the effect of p-DCD on distensibility is different for males and females. To better understand this difference, we graphed the association between sex, p-DCD and distensibility using the regression equation from Table 4.6. It can be seen in Figure 4.2, that distensibility in the p-DCD males is lower than in the controls while distensibility in the p-DCD females is higher compared to controls.

Table 4.6 Multivariate linear regression of p-DCD on PWV and distensibility

	R	R^2	$R^2_{adjusted}$	$b_{unstandardized}$	$B_{standardized}$	P value
PWV	**(n=46)**					
Model 1	**0.279**	**0.078**	**0.065**			
Constant				3.828		0.000
p-DCD				0.169	0.280	0.016
Model 2	**0.436**	**0.190**	**0.156**			
Constant				3.819		0.000
p-DCD				0.284	0.469	0.001
Sex				0.021	0.034	0.803
Sex*p-DCD				-.361	-.400	0.010
Distensibility	**(n=45)**					
Model 1	**0.101**	**0.010**	**-0.003**			
Constant				0.008		0.000
p-DCD				0.000	-.101	0.389
Model 2	**0.329**	**0.108**	**0.071**			
Constant				0.008		0.000
p-DCD				-.001	-.334	0.022
Sex				-.001	-.344	0.017
Sex*p-DCD				0.002	0.414	0.013

PWV = Pulse Wave Velocity, p-DCD = Potential Developmental Coordination Disorder. Regression involving PWV had a sample size of 46 while those involving distensibility had a sample size of 45.

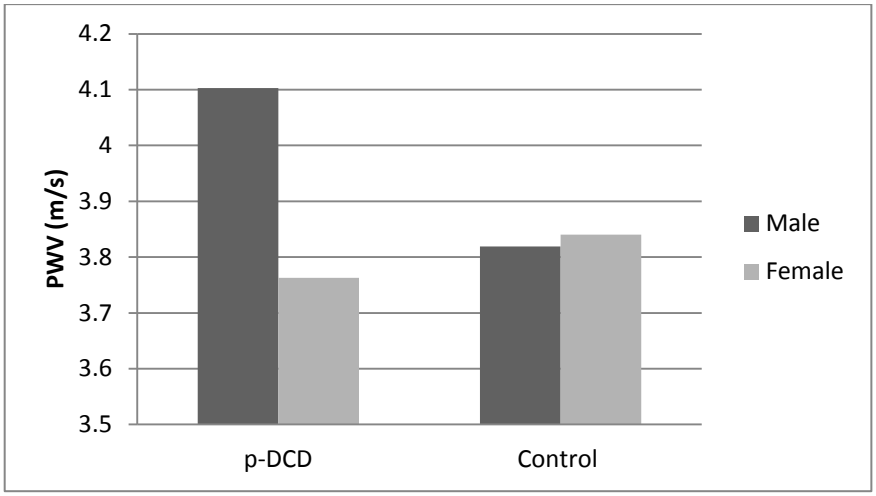

Figure 4.1 Interaction between sex and DCD/control status with respect to PWV

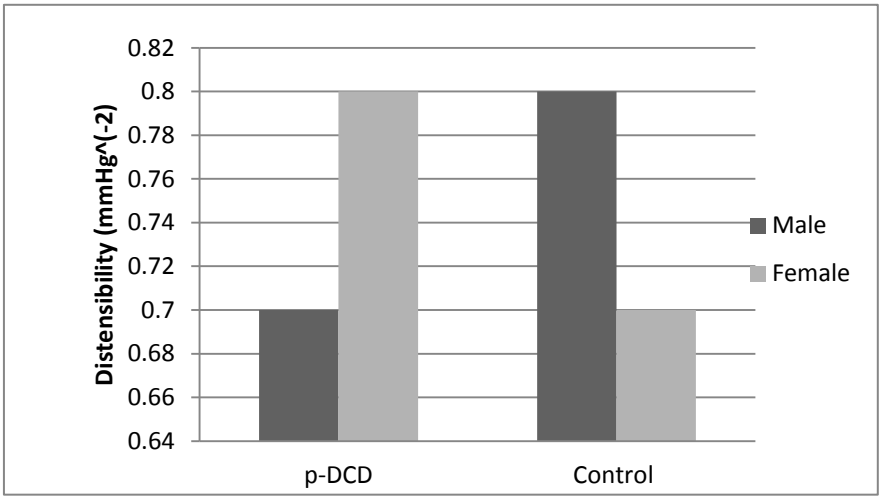

Figure 4.2 Interaction between sex and p-DCD/control status with respect to distensibility

4.4.0 Covariate Adjusted Multivariate Linear Regressions of p-DCD on Pulse Wave Velocity and Distensibility

Because p-DCD was found to be related to PWV and distensibility in males, we conducted a series of regressions attempting to see what might account for or explain the effects of p-DCD on PWV and distensibility in males.

PWV and distensibility were analyzed based on six models; 1) effect of p-DCD on PWV, 2) model 1 plus HR, 3) model 2 plus SBP 4) model 3 plus PBF, 5) model 3 plus VO_{2FFM}, and 6) model 3 plus maturation. Significance was set at $p<0.05$. Models were chosen based on Spearman correlations and known factors affecting arterial stiffness.

In the first model (Table 4.7), examining p-DCD and PWV, the main effect of p-DCD was positive and significant (p=0.001). When HR was entered into model 2, the main effect of p-DCD on PWV remained significant (p=0.004). This effect also remained significant when SBP was entered in model 3 (p=0.008), VO_{2FFM} was entered in model 5 (p=0.025) and maturation was entered in model 6 (p=0.006). When PBF was entered into model 4, the main effect of p-DCD on PWV was no longer significant (p=0.074).

Models 1, 2 and 3 accounted for 21.8%, 22.3% and 23.8% of the variability in PWV respectively. Models 4, 5 and 6 were similar and accounted for 22.6%, 26.4% and 27.7% of the variability respectively. None of the covariates, HR, SBP, PBF, VO_{2FFM}, and maturation were significant predictors of PWV.

Table 4.7 Covariate adjusted multivariate linear regression for PWV in males with and without p-DCD (n=46)

	R	R^2	$R^2_{adjusted}$	$b_{unstandardized}$	$B_{standardized}$	P value
Model 1	**0.485**	**0.236**	**0.218**			
Constant				3.819		0.000
p-DCD				0.284	0.485	0.001
Model 2	**0.507**	**0.257**	**0.223**			
Constant				3.560		0.000
p-DCD				0.249	0.426	0.004
HR				0.004	0.158	0.270
Model 3	**0.538**	**0.289**	**0.238**			
Constant				3.024		0.000
p-DCD				0.231	0.396	0.008
HR				0.003	0.133	0.351
SBP				0.005	0.185	0.177
Model 4	**0.543**	**0.295**	**0.226**			
Constant				3.012		0.000
p-DCD				0.195	0.333	0.074
HR				0.003	0.136	0.346
SBP				0.005	0.178	0.199
PBF				0.002	0.097	0.580
Model 5	**0.574**	**0.330**	**0.264**			
Constant				3.381		0.000
p-DCD				0.197	0.337	0.025
HR				0.002	0.069	0.635
SBP				0.007	0.232	0.095
VO_{2FFM}				-.007	-.225	0.123
Model 6	**0.588**	**0.346**	**0.277**			
Constant				2.489		0.000
p-DCD				0.246	0.411	0.006
HR				0.004	0.151	0.294
SBP				0.008	0.253	0.067
Maturation				0.036	0.115	0.391

p-DCD = Potential Developmental Coordination Disorder, HR = Heart Rate, SBP = Systolic Blood Pressure, PBF = Percent Body Fat, VO_{2FFM} = Maximal Aerobic Fitness Normalized to Fat Free Mass

The regression analysis for distensibility on p-DCD can be seen in Table 4.8. In the first model, the main effect of p-DCD was positive and significant (p=0.001) accounting for 7.9% of the variability in distensibility. When HR was entered into model 2, SBP in model 3, PBF in model 4, VO_{2FFM} in model 5, and maturation in model 6, the main effect of p-DCD on distensibility was no longer significant (p=0.068, p=0.146, p=0.852, p=0.234 and p=0.190 respectively). Model 2 accounted for 11.3% of the variability in distensibility. Models 3, 4, and 5 accounted for slightly more variability in distensibility with 15.8%, 22.3%, and 14.4% respectively and model 6 accounted for 7.2%. PBF was a significant predictor of distensibility (p=0.46) while HR, SBP, VO_{2FFM}, and maturation were not.

Table 4.8 Covariate adjusted multivariate linear regression for distensibility in males with and without p-DCD (n=45)

	R	R^2	$R^2_{adjusted}$	$b_{unstandardized}$	$B_{standardized}$	P value
Model 1	**0.316**	**0.100**	**0.079**			
Constant				0.008		0.000
p-DCD				-.001	-.316	0.034
Model 2	**0.394**	**0.156**	**0.113**			
Constant				0.011		0.000
p-DCD				-.001	-.285	0.068
HR				-3.322E-005	-.203	0.189
Model 3	**0.467**	**0.218**	**0.158**			
Constant				0.16		0.000
p-DCD				-.001	-.225	0.146
HR				-2.886E-005	-.176	0.243
SBP				-5.081E-005	-.261	0.085
Model 4	**0.545**	**0.297**	**0.223**			
Control				0.016		0.000
p-DCD				0.0001	-.033	0.852
HR				-3.069E-005	-.187	0.197
SBP				-4.134E-005	-.212	0.148
PBF				-6.349E-005	-.349	0.046
Model 5	**0.475**	**0.225**	**0.144**			
Constant				0.014		0.000
p-DCD				-.001	-.195	0.234
HR				-2.247E-005	-.137	0.408
SBP				-5.266E-005	-.270	0.079
VO_{2FFM}				1.938E-005	0.100	0.561
Model 6	**0.409**	**0.167**	**0.072**			
Constant				0.015		0.000
p-DCD				-.001	-.219	0.190
HR				-2.848E-005	-.180	0.275
SBP				-4.118E-005	-.197	0.223
Maturation				-5.204E-006	-.003	0.986

p-DCD = Potential Developmental Coordination Disorder, HR = Heart Rate, SBP = Systolic Blood Pressure, PBF = Percent Body Fat, VO_{2FFM} = Maximal Aerobic Fitness Normalized to Fat Free Mass

Chapter 5: Discussion

5.1.0 Introduction

The purpose of this study was to investigate arterial health in children with and without DCD. As both arterial health and DCD have been shown to vary between sexes (Ahimastos et al. 2003; Cairney et al. 2005b), we have examined arterial stiffness and thickness among males and females with p-DCD and compared them to age and school matched controls. To the author's knowledge, this is the first study to examine arterial health in this population. We hypothesized that children with p-DCD would have increased arterial stiffness and thickness as measured by compliance, distensibility, PWV and IMT. In addition, we hypothesized that arterial stiffness and thickness would be greater in males. The principle findings of this study indicate that male children with p-DCD have higher PWV and reduced distensibility compared to controls, while female children with p-DCD have no significant differences in arterial health measures compared to controls. The higher PWV and distensibility in p-DCD males may be attributed to a higher PBF as it negated the main effect on PWV and was a significant predictor of distensibility. In addition, it was found that male children with p-DCD experienced significant differences in cardiovascular measures of HR and peak VO_{2FFM}, while female children with p-DCD experienced significant differences in peak VO_2 and peak $VO_{2FFM.}$

5.2.0 Arterial Parameters

Arterial stiffness is especially important to study as it has been shown to be a surrogate marker of atherosclerosis (Cecelja & Chowienczyk, 2012). In addition, arterial

stiffness is an important predictor of CVD in adults and of CVD risk factors in children (Sakuragi et al. 2009). When arterial stiffness and thickness were analyzed separately by sex, it was evident that sex differences were present. It was found that males with p-DCD had significantly faster PWV and lower arterial distensibility compared to controls, while females showed no differences. The lack of difference seen in females may be a result of limited power as there were only 10 females with p-DCD.

It has been shown that females tend to participate less in physical activity than males (Telama et al. 2004). As well, Batey and colleagues (2013) found that male children with p-DCD had significantly different physical activity levels compared to controls while females did not. Therefore, although we did not measure physical activity, the female controls in this study most likely had low physical activity levels, resulting in no difference between p-DCD females and controls. Conversely, males with p-DCD most likely had substantially lower physical activity levels than male controls, resulting in large differences between the groups. As a result, the difference in physical activity between the males may have impacted arterial health causing significant differences between groups, while no differences were seen in the females. This hypothesis is supported by the relationship between physical activity and PWV and distensibility. Edwards and colleagues (2012) examined the effects of physical activity on arterial health measures of carotid-femoral PWV and brachial artery distensibility in 156 adolescents and young adults. Participants were assigned to a low, middle, or high tertile of physical activity. It was found that PWV was significantly lower and brachial

artery distensibility was significantly higher in the high physical activity group suggesting that increased activity has positive effects on arterial health.

Furthermore, obesity has been shown to alter arterial structure and function in children (Tounian et al. 2001). Banach and colleagues (2010) examined the differences in arterial distensibility of the right CCA in 38 males and 27 females between the ages of 9 and 12 years. Children were grouped into normal weight and overweight groups and arterial distensibility was found to be significantly lower in children who were overweight. As a result, with respect to the current study, the significant differences in PBF between children with p-DCD and controls may explain the removal of the main effect of p-DCD on PWV in males when PBF was added to the multivariate regression model.

In addition, this study reports similar findings to that of Ahimastos and colleagues (2003) who found that post-pubertal males had stiffer arteries compared to age matched females. In the current study, males with p-DCD were found to have greater PWV compared to male controls, females with p-DCD and female controls. In addition, the current study found that males with p-DCD had lower distensibility compared to male controls and females with p-DCD. These findings suggest that sex differences exist in arterial health measures and that males with p-DCD have stiffer arteries compared to females with p-DCD. Conversely, others have found no sex related differences in arterial stiffness (Jourdan et al, 2005; van der Heijden-Spek et al. 2000). Differences between studies may be attributed to how stiffness was measured. As a

result, arterial health measures of PWV, distensibility, compliance, and IMT are discussed in more detail below.

5.2.1 Pulse Wave Velocity

The ability of the arteries to cushion blood flow is determined by the elasticity of the arterial walls, which can be estimated by PWV (London & Guerin, 1999). As arteries stiffen, the pulse wave transmitted throughout the arterial tree becomes faster which in turn increases PWV (Schiffrin, 2004).

The results from this study indicate that male children with p-DCD have significantly increased R-wave-to-toe PWV compared to age and school matched controls. This difference remained after controlling for HR, SBP, VO_{2FFM} and maturation. In addition, male children with p-DCD had significantly higher FM and lower VO_{2FFM}. Furthermore, PWV was positively correlated with SBP and HR. These findings are not surprising as BP has been shown to influence PWV. Chronically elevated BP may lead to altered arterial structure such as increased collagen synthesis which leads to faster pulse wave propagation (Nichols & O'Rourke, 2005). Furthermore, HR is known to alter the peak of the forward travelling wave – with slower HR causing a delay in the peak of the wave (Dart & Kingwell, 2001). As a result, PWV is affected as pulse transit time is altered.

Moreover, it has been shown that obese children have increased PWV compared with their lean peers (Celik et al. 2011). In addition, it has been shown that children who have lower aerobic fitness also have increased PWV compared to controls (Tanaka et al. 1998). The findings of the present study therefore are not surprising as male children

with p-DCD have a higher FM, PBF and have lower aerobic fitness, which would suggest that they should also have increased PWV.

While a significant difference was seen in PWV between males with p-DCD and male controls, the values reported in this study match those of only one other child study. The differences between our values and others reported in the literature are likely due to the different techniques used to measure PWV in children. In the literature, the values for central PWV are approximately 5m/s when measuring from the CCA to the femoral artery in children (O'Rourke and Mancia, 1999). Currie and colleagues (2010) however, measured whole-body PWV from the R-wave of the ECG to the toe, and report PWV values of 3.5m/s ± 0.3 in children aged 4 years. Our values for PWV (3.8 and 4.1m/s) are slightly higher likely due to differences in age between the children in our study and those in Currie and colleagues (2010). As well, while our values for PWV in males are slower than 5m/s, they may still be clinically relevant as we measured whole-body and not central PWV. This technique (R-wave-to-toe) yields slower PWV measures because it incorporates the time it takes for the heart to contract and eject blood which in turn, increases transit time. As well, this technique incorporates both systemic and central arterial stiffness. Clinically relevant values associated with the R-wave-to-toe technique are not currently available; therefore more research is needed in order to determine clinically relevant cut points using the R-wave-to-toe method.

Measuring PWV using the R-wave-to-toe method has shown to be as feasible as taking beat-by-beat recordings of the pulse wave at the femoral artery (Currie et al. 2010) which was not a practical option in our population. This method is not only less

time consuming but is also less dependent on operator skill and patient compliance compared with the traditional carotid-to-femoral method of measuring PWV. In addition, the R-wave-toe technique may be useful for large scale studies of arterial health in child populations such as this one.

5.2.2. Compliance and Distensibility

Compliance and distensibility are used to measure the elastic properties of the arterial wall. Compliance is the tendency of the vessel to resist recoil towards its original dimensions and is dependent on artery size. During childhood, normal development includes increases in arterial growth and changes in lumen diameters (Fernhall & Agiovlasitis, 2008). As a result, compliance must be interpreted with caution in child populations. In this study, CCA compliance was not significantly different between children with p-DCD and controls for either sex. This is contradictory to findings by Juonala and colleagues (2005) who examined CCA compliance in healthy adults aged 24 to 39 years who were exposed to childhood risk factors for CVD such as obesity and elevated BP. They found that childhood SBP and skinfold thickness were significantly associated with carotid artery compliance. Differences may be attributed to age related changes in arterial health as our sample has a mean age of 14.5 years compared to 31.7 years. In addition, natural changes to arterial structure and lumen diameter occur with growth and therefore may conceal any true difference between arterial structure in those with and without p-DCD.

Conversely, distensibility is the ability of the artery to stretch under pressure and represents the change in vessel diameter for a given change in pressure. Distensibility is

not dependent on artery size and estimates arterial stiffness in a localized region within the arterial vasculature. In this study, distensibility was significantly lower in males with p-DCD compared to controls. When controlling for covariates, this difference was no longer significant, while PBF was the only significant predictor of distensibility.

The correlations between distensibility and various independent variables are supported by Jourdan and colleagues (2005). In their study, distensibility coefficient was found to be negatively correlated with age, BMI, SBP and brachial PP. In the current study, age was controlled for through matching; however, PBFSBP, MAP and PP were all negatively correlated with distensibility, indicating that increases in PBFSBP, MAP and PP are all related to decreases in arterial distensibility.

Finally, males with p-DCD had higher diastolic diameters compared to controls. This finding is similar to a study by Tounian and colleagues (2001) who found an increase in diastolic diameter and a decrease in distensibility in 48 obese children when compared to controls. This suggests that body size affects arterial structure and that arterial remodeling may have begun in males with p-DCD.

5.2.3 Intima-Media Thickness

Increased IMT is considered to be one of the first signs of atherosclerosis brought on by damaging factors such as hypertension, lipids (Jarvisalo et al. 2004), homocysteine or certain infectious agents (Megnien et al. 1998). Normal developmental changes in arterial structure in children are small. A cross-sectional study examining the age trends on IMT shows significant changes over a 2 to 4 year period (Bohm et al. 2009). The current study found no significant differences in CCA IMT between children

with p-DCD and controls for either sex. This is in contrast to studies examining the effects of obesity (Meyer et al. 2006) and hypertension (Litwin et al, 2004), who showed that carotid and femoral IMT was significantly elevated in both males and females aged 5-20 years. Discrepancies between studies may be attributed to differences between sample characteristics such as BP, and BMI and are discussed in more detail below.

Litwin and colleagues (2004) reported SBP levels between 129mmHg and 131mmHg. In the current study, SBP is reported at 110mmHg and is not significantly different between groups. A higher SBP would likely lead to an increased IMT as SBP is a dominant predictor of atherosclerosis and has been shown to relate to IMT even when DBP does not. As a result, it appears that SBP in the current study is not elevated enough to cause structural changes to the arterial wall.

Meyers and colleagues (2006) examined obesity and IMT in children (aged 9 to 16 years) whose mean BMI was 30.6 compared to controls at 20.4kg/m^2. In the current study, p-DCD children had a mean BMI of 25.6 while controls had a mean BMI of 21.3. In comparing studies, controls have similar IMT values (Meyers, IMT = 0.39; Current, female IMT = 0.39, male IMT = 0.40), while obese and p-DCD groups do not (Meyers, IMT = 0.49; Current, IMT = 0.39 for both males and females). Hence, differences in IMT may take longer to manifest in children who are overweight (as in the current study) compared to those who are obese.

5.3.0 Anthropometry

In addition to changes in arterial health parameters, both male and female children with p-DCD exhibit increased PBF compared to controls. PBF was measured

using air displacement plethysmography using the BOD POD which is an accurate method for determining fat mass and lean muscle mass in children (Fields et al. 2002). The current finding is supported in the literature in children with DCD (Faught et al. 2005; Hands & Larkin, 2002). This result is not surprising as children with DCD have been shown to have lower self-efficacy with respect to physical activity. In addition, they have also been shown to participate less in group and free-play activities (Cairney et al. 2005c). Reduced participation in physical activity is correlated with increased body mass and PBF, and therefore it is expected that children with DCD would have increased PBF.

Furthermore, in the current study significantly lower aerobic fitness after normalizing to FFM was seen in children with p-DCD compared to controls. This is supported by the literature. Wu and colleagues (2010) used peak VO_2, as estimated by the Bruce treadmill protocol, to determine cardiorespiratory fitness. They found that CRF was significantly lower in children with DCD compared to controls (39.7ml/kg/min vs. 47.6ml/kg/min, respectively). Values reported in this study (52.4 ml/kg_{FFM}/min and 58.4 ml/kg_{FFM}/min) are slightly higher than those presented by Wu and colleagues (2010) which may be attributed to methods of measuring peak aerobic power, as well as the normalization to FFM

Finally, HR was significantly higher in the p-DCD males compared to controls. In the literature, HR has been found to be significantly higher in children with p-DCD (Chirico et al. 2011) while others have found no significant differences between high and low motor competence groups (Cantell et al. 2008). Perhaps discrepancies in the literature are a result of differences between the sexes with respect to this measure. It

has been previously shown by Batey et al. (2013) that males with p-DCD participate in significantly less physical activity than their TD peers while no differences are seen between females with p-DCD and controls. As a result, males controls would be expected to have significantly lower HR than males with p-DCD as increased physical activity has been shown to reduce HR (Rennie, et al. 2003).

5.4.0 Limitations

Although the current study adds new knowledge to the literature, there are recognizable limitations that need to be highlighted. First, we were unable to confirm whether the motor impairments experienced by children with DCD significantly interfered with activities of daily living (ADLs) and/or academic performance. As a result, we were unable to meet the full criteria of the DSM-V and therefore identified children as having p-DCD. Secondly, because this is a cross-sectional study within a larger longitudinal study, we cannot make causal links between p-DCD and cardiovascular risk. Tracking arterial changes over time in children with p-DCD will provide a better understanding of how arterial structure and function are altered in this population. Thirdly, the number of females in the p-DCD group was low (n=10). As a result, there was not enough power (power=34) to detect significant changes within this group and therefore we cannot say for certain whether arterial changes are present within this population. Finally, maturation was self-reported using Tanner Staging. While the Tanner Scale is widely used and reliable we cannot be certain that children circled the correct developmental stage.

5.5.0 Future Considerations

Future studies should look at arterial health in children with p-DCD over time. In the current study, arterial health was measured at one point in time and significant differences were seen in males with p-DCD compared to controls. Following children with p-DCD through time would allow for the detection of when arterial changes occur in these children. In addition, a larger sample of females with p-DCD would be beneficial to better examine arterial health within this sub-population. In addition, the changes in arterial health within this population may be more pronounced as the children age.

More research is needed to test the effectiveness of the R-wave-to-toe technique in children as there are a number of factors that may influence this measure of PWV including age, maturation and obesity. Furthermore, given that children with DCD tend to be overweight and obese, less physically active and less physically fit, it might be beneficial to implement an intervention study. Studies have shown that DCD persists into adulthood and starting children on an intervention may help to minimize motor impairments in adulthood.

5.6.0 Conclusions

This is the first study to examine arterial health in children aged 14 to 15 years with p-DCD. Males with p-DCD showed significant differences in arterial health indices of PWV and distensibility, while females did not. As a result, it is apparent that sex differences exist with respect to arterial health within this population and that children with p-DCD may be more likely to develop arterial stiffness later in life.

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Appendix A

Research Ethics Approval

DATE: January 10, 2008

FROM: Michelle McGinn,
Chair Research Ethics Board (REB)

TO: Brent FAUGHT, CHSC

FILE: 07-106 FAUGHT

TITLE: Establishing the Health Profile of Children with Motor Coordination Challenges

The Brock University Research Ethics Board has reviewed the above research proposal.

DECISION: Accepted as clarified

This project has received ethics clearance for the period of January 10, 2008 to December 30, 2011 subject to full REB ratification at the Research Ethics Board's next scheduled meeting. The clearance period may be extended upon request. ***The study may now proceed.***

Please note that the Research Ethics Board (REB) requires that you adhere to the protocol as last reviewed and cleared by the REB. During the course of research no deviations from, or changes to, the protocol, recruitment, or consent form may be initiated without prior written clearance from the REB. The Board must provide clearance for any modifications before they can be implemented. If you wish to modify your research project, please refer to http://www.brocku.ca/researchservices/forms to complete the appropriate form Revision or Modification to an Ongoing Application. Adverse or unexpected events must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Principal Investigator, the safety of the participants and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-Council Policy Statement requires that ongoing research be monitored. A Final Report is required for all projects upon completion of the project. Researchers with projects lasting more than one year are required to submit a Continuing Review Report annually. The Office of Research Services will contact you when this form *Continuing Review/Final Report* is required.

Please quote your REB file number on all future correspondence.

Office of Research Ethics, MC D250A

Brock University
Office of Research Services
500 Glenridge Avenue
St. Catharines, Ontario, Canada L2S 3A1

Appendix B

Child Letter of Informed Consent

Principal Investigators: Dr. John A. Hay, Brock University
Dr. John Cairney, University of Toronto & Brock University
Dr. Brent E. Faught, Brock University

Dear Parent and Child:
Thank you for your interest in our study. Please read the following information together. If you both feel comfortable and willing to participate in the tests described below, please check the boxes at the end of this consent form indicating child and parent consent.

Purpose: The purpose of this study is to look at healthy growth and development of children for the next three years.

Procedures: This assessment will take approximately 2.5 to 3 hours long and is divided into three parts. We thank you for participating. As promised, we have agreed to provide transportation for you to and from Brock University as well as $50 ($20 for lab measures and $30 for home measures) for your family's participation in this study. Your participation is voluntary and you are free to withdraw from this study at any time without penalty from Brock University. Further, you are under no obligation to answer any or all questions or to participate in any aspect of this project. If you wish to stop participating in this study at any time, you and your parent will still receive free transportation from us as well as $20 for your participation in the lab measures. Each part is described below.

PART I
This part of the study will be conducted in our laboratory at Brock University and requires 2.5 to 3 hours of your time. First, we would like you to complete the following forms, which will take about 10 minutes.

1. Medical Screening Questionnaire
2. Edinburgh Survey – Handedness Questionnaire

Next, we would like to complete a number of physical assessments on your child with the parent/guardian present. These assessments include:

1. **Body composition:**
    a. Height and weight will be measured using a dual purpose stadiometer.
    b. 9 skinfold sites using painless pinch calipers. (It does not hurt).
    c. Measure around the waist and hip using a flexible tape measure.
    d. Bioelectric impedence analysis requires your child to stand on a weight scale and grasp handles. An electrical impulse travels from your child's hands to their feet. The impulse cannot be felt and causes no harm.
    e. Lengths of your child's ring and index fingers.
    f. Body muscle and fat weight will be measured while your child sits in the BOD POD chamber. If your child expressing previous or current anxiety for confined spaces, they will not be allowed to participate in this portion of the study. The

BOD POD incorporates a built in window on the front of the chamber in the event of a claustrophobic event or for communication purposes as well as a safety latch on the inside of the chamber for the subject to voluntarily exit on their own. During this 5-minute assessment, your child will be asked to relax and breathe normally.

2. **Cardiovascular health measures:** The carotid ultrasound method will be performed using a probe and pen like-devices. Heart rate will be measured using sensors placed on the skin of your child's chest. These sensors are used to detect the electrical activity generated by the heart and are not used to transmit electrical signals into their body from the heart rate monitor. Blood pressure is monitored using an automated arm cuff system that is similar to the method used in a doctor's office. A cuff is wrapped around the upper arm and is inflated then deflated. No risk is involved.
3. **Movement ABC^2 assessment:** This motor coordination assessment involving 8 short activities, including tasks such as tracing, cutting on a line and throwing a ball.
4. **Physical fitness assessment:** This assessment uses a bicycle to measure the maximum amount of heavy exercise. The bicycle tension will gradually get more difficult to pedal. A mask over the mouth and nose will be used to collect oxygen and carbon dioxide. The assessment will be finished when your child decides. One of the common risks of this assessment is the brief sensation of exhaustion. At the end of the assessment, your child will be asked to continue to pedal the bicycle at a very easy level until this sensation goes away. The risk of serious illness or death is extremely rare and is reduced by completing the medical screening questionnaire before the assessment and the continuous monitoring we will perform during the assessment.
5. **Accelerometer assessment:** This assessment will require your child to wear a small box the size of a smaller pager clipped onto their pant waist. The accelerometer is designed to measure activity movement that your child performs. We wish for your child to wear the accelerometer from the time they wake up, until the go to bed at night for 7 days. We also ask that the parent complete the Habitual Activity Estimation Scale and our Activity Log. There is no risk associated with this assessment. We will make arrangements to pick the accelerometer unit at your home.

PART II

The second part of the study would take place approximately 7 days from now at your home. We would come in the morning (before your child has breakfast) and it will only take about 10 minutes. We wish to collect a sample of your child's blood using a finger pinprick technique. The middle finger of your child's non-dominant hand (e.g. if they are right handed, we will use the middle finger of their left hand) will be pricked so two drops of blood can be sampled. Your child will feel a small prick, but will not feel any pain or discomfort for the remainder of the assessment. The tip of that finger may feel sensitive and a little bit sore for about a day. It is important to keep the site clean and covered with an adhesive bandage until it is healed to reduce the risk of infection. We will also use this moment to pick up the accelerometer that you will have had for the past week.

PART III

For this part of the study we would like you to allow your child's homeroom teacher complete a survey on your child's combined listening, speaking, reading, writing, mathematics and reasoning skills. The name of this survey is the Learning Disabilities Diagnostic Inventory. Despite the name of this survey, we are not looking to diagnose any disabilities in your child's learning ability, nor is

the teacher expected to provide a learning disabilities' diagnosis. We simply wish to see how able your child is while learning at school. The results of this assessment will not be shared with your child's school.

Participation and Withdrawal: Your child's participation is voluntary and they are free to withdraw from this study at any time without penalty from Brock University. Further, your child is not required to answer any or all questions or to participate in any aspect of this project.

Confidentiality: All personal data will be kept strictly confidential and all information will be coded so that your child is not associated with their answers. Only the researchers named above will have access to the complete data. Any information we receive will be entered immediately into computer records using a code number with no name attached. It is our intent to continue to publish the results of this research in scientific journals. Again, no personal information will be identified or be possible within any publication.

Information: This study has been reviewed and approved by the Brock University Research Ethics Board, (File#: 07-106) Research Services, Brock University, Room C315 - 905-688-5550 (Ext. 4315). We greatly appreciate your co-operation. If you would like to receive more information about the study, please contact **Dr. Brent E. Faught** at 905-688-5550, (Ext. 3586). If you are willing to grant permission to participate in this study, please complete the consent form below.

Thanks for your help!

Brent E. Faught, Ph.D. John A. Hay, Ph.D. John Cairney, Ph.D.

PARENT CONSENT FORM

I have read and understand the above explanation of the purpose and procedures of the project. My questions have been answered to my satisfaction.

- ☐ I give permission for my child to participate in **Part I** of the Brock University study conducted by Dr. John Hay, Dr. John Cairney and Dr. Brent E. Faught.

- ☐ As the participating child, I wish to participate in **Part I** of the Brock University study conducted by Dr. John Hay, Dr. John Cairney and Dr. Brent E. Faught.

- ☐ I give permission for my child to participate in **Part II** of the Brock University study conducted by Dr. John Hay, Dr. John Cairney and Dr. Brent E. Faught.

☐ As the participating child, I wish to participate in **Part II** of the Brock University study conducted by Dr. John Hay, Dr. John Cairney and Dr. Brent E. Faught.

☐ I give permission for my child to participate in **Part III** of the Brock University study conducted by Dr. John Hay, Dr. John Cairney and Dr. Brent E. Faught.

☐ As the participating child, I wish to participate in **Part III** of the Brock University study conducted by Dr. John Hay, Dr. John Cairney and Dr. Brent E. Faught.

OR

☐ I do **NOT** give permission for my child to participate in the Brock University study conducted by Dr. John Hay, Dr. John Cairney and Dr. Brent E. Faught.

☐ As the participating child, I do **NOT** wish to participate in the Brock University study conducted by Dr. John Hay, Dr. John Cairney and Dr. Brent E. Faught.

Signature of Parent/Guardian: _____ Date: _____

Signature of Student: _____ Date: _____

Appendix C

Advanced Health Assessment Information Sheet

Date: _____ Time (am/pm): _____

SECTION 1: STUDENT INFORMATION		
Student ID #: ____ ____ ____ ____ ____ ____ ____ ____ ____	**Name:**	
Gender: Male Female	**DOB:** ___ ___ / ___ ___ / ___ ___ ___ ___ (month) (day) (year)	**Age:** _____
Height (cm): _____ **cm**	**Weight (kg):** _____ **kg**	**BMI:** _____ **(kg/m²)**

SECTION 2: CONSENTS and QUESTIONNAIRES	
STUDENT (check for completeness)	**PARENT (circle for completeness)**
1. Consent (signed): _____	1. Consent (signed): _____
2. Medical Screening Questionnaire: _____	2. Medical Academic History Questionnaire: _____
3. Edinburgh Survey: _____	3. Conner's Parent Rating Scales: _____
4. Tanner Questionnaire: _____ OR complete at home: _____	4. Edinburgh Modified Parent Survey: _____
5. Accelerometer and Pkg (given) : Y _____ N (no consent) _____	5. Habitual Activity Estimation Scale: _____
6. Teacher Package (given) : Y _____ N (no consent) _____	6. Hypermobility Questionnaire: _____
7. Tanner Questionnaire Completed: Y _____ N _____	7. Accelerometer Log Completed: Y _____ N _____
8. "Two Days in My Life" Completed: Y _____ N _____	8. "Two Days in My Child's Life" Completed: Y _____ N _____
9. Teacher Package Completed: Y _____ N _____	9. Consent and Questionnaires Filled Out By: _____
Comments:	

SECTION 3: BODY COMPOSITION MEASURES	
Waist Circumference	**Hip Circumference**
Examiner:	
Trail #1**:** _____ **cm**	Trail #1**:** _____ **cm**
Trail #2**:** _____ **cm**	Trail #2**:** _____ **cm**
Mean: _____ **cm**	Mean: _____ **cm**
Waist / Hip Ratio and Percentage	
Ratio: _____	Percentage: _____
Bioelectric Impedence Analysis	
Examiner:	
Lean Body Mass: _____ **kg**	Percent Body Fat**:** _____ %
Body Fat Mass: _____ **kg**	Basal Metabolic Rate**:** _____ kcal

SECTION 3 CONTINUED: BODY COMPOSITION MEASURES				
Skinfold Measurements				
Examiner:				
SITE	**TRIAL 1 (mm)**	**TRIAL 2 (mm)**	**TRAIL 3 (>1mm)**	**MEAN (mm)**
BICEPS				
TRICEPS				
CHEST				
SUBSCAPULAR				
MID-AXILLARY				
SUPRA-ILIAC				
ABDOMEN				
THIGH				
MEDIAL CALF				
SUM OF SKIN FOLDS: _____ **(mm)**				

PERCENT BODY FAT (3 site – Jackson and Pollock): _____ **(%)**	
PERCENT BODY FAT (4 site – Durnin and Wormersley): _____ **(%)**	
PERCENT BODY FAT (7 site – Jackson and Pollock): _____ **(%)**	
BOD POD	
Examiner:	
Fat Mass: _____ **kg**	Percent Body Fat**:** _____ **%**
Fat Free Mass: _____ **kg**	Body Volume**:** _____ **L**
Body Mass: _____ **kg**	Body Density**:** _____ **kg/L**
Thoracic Gas Volume**:** _____ **L**	
Digits	
Examiner:	
RIGHT HAND	**LEFT HAND**
Digit #2 (pointer finger): _____ **(mm)**	Digit #2 (pointer finger): _____ **(mm)**
Digit #4 (ring finger): _____ **(mm)**	Digit #4 (ring finger): _____ **(mm)**
Right Hand Ratio (D2/D4): _____	Left Hand Ratio (D2/D4): _____

SECTION 4: ARTERIAL MEASUREMENTS		
Doppler Settings		
Examiner:		
Frequency: 10.0 mHz	Power: 0 dB	
Depth: _____ **cm**		
FPS: change focus # (decrease to 2) to increase fps	Persistence: turn to minimum	
Blood Pressure – Manual		
	Systole (mmHg)	**Diastole (mmHg)**
Pre 1		
2		

3		
Post 1		
2		
3		

Distance Measurements	
Sternal notch to toe: _____ **cm**	Sternal notch to carotid: _____ **cm**

Notes for Cardiovascular Component

SECTION 5: LEFT VENTRICULAR MASS MEASUREMENTS	
Examiner:	
Probe: _____	Depth: _____ **cm**
B-Mode Images:	M-Mode Images:

SECTION 5 CONTINUED: LEFT VENTRICULAR MASS MEASUREMENTS	
Interventricular Septum (end-diastole): _____	Ejection Fraction: _____
Left Ventricular Diameter (end-diastole): _____	Circumferential Shortening: _____

Posterior Wall (end-diastole): _____	LVM: _____
Left Ventricular Diameter (end-systole): _____	

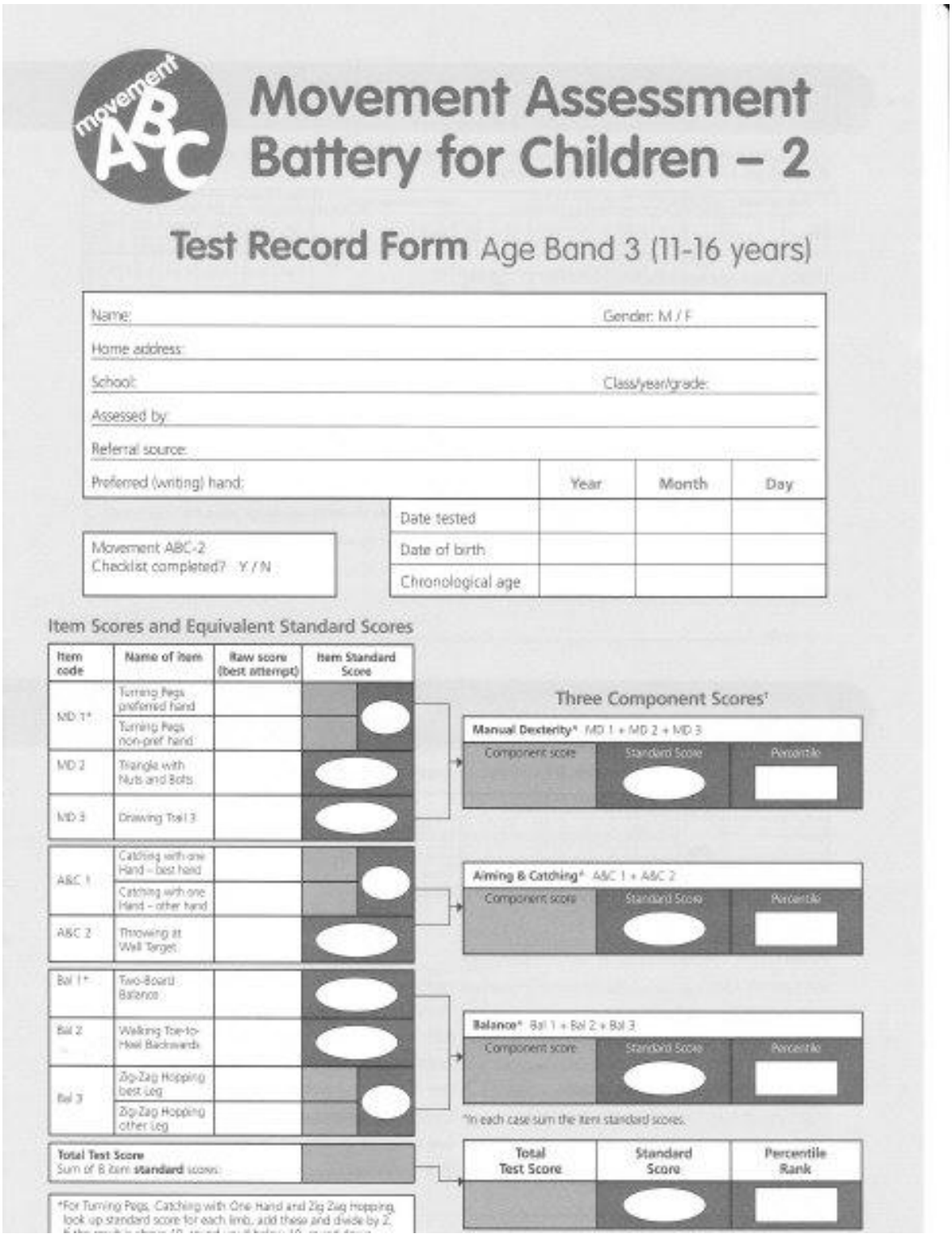
SECTION 6: VO_2 MAX	
Examiner:	
Bike Instructions	
RPM: 60 – 80 rpm	Begin Test: 20 watts
Increment Changes: 20 watt increase every 2 minutes	Finish Test: volitional drop out; heart rate reaches max (220-age), expiratory ratio is ≥ 1.1, or of the VO_2 peak plateaus
Heart Rate	
Rest: **_____ bpm**	_____W: **_____ bpm**
_____W: **_____ bpm**	_____W: **_____ bpm**
_____W: **_____ bpm**	_____W: **_____ bpm**
_____W: **_____ bpm**	_____W: **_____ bpm**
_____W: **_____ bpm**	_____W: **_____ bpm**
Final VO_2: **_____ ml/kg**	
MAX Heart Rate: **_____ b/min**	Final Duration: **_____ min**
Watts: **_____ W**	Final Stage: _____
Final RER: _____	Last RPE Report: _____
Notes: (Please note any changes to protocol, problems during testing, medical conditions that would hinder test results)	

SECTION 7: BLOOD ANALYZER	
TC: **_____ mg/dL**	Non-HDL: **_____ mg/dL**
HDL: **_____ mg/dL**	TC/HDL: **_____ mg/dL**

TRG: _____ **mg/dL**	GLU: _____ **mg/dL**
LDL: _____ **mg/dL**	GLU: _____ **mmol/L**
Notes: (Please note any changes to protocol, problems during testing, other circumstances that would hinder test results)	
EXTRA MEASURMENTS:	
Section 4 Continued: Arterial Measurements	
Diastolic Diameter: _____ **mm**	Heart Rate: _____ **bpm**
Systolic Diameter: _____ **mm**	Automated Systolic Arterial Pressure: _____ **mmHg**
Diameter Change: _____ **mm**	Automated Diastolic Arterial Pressure: _____ **mmHg**
Carotid Pulse Pressure: _____ **mmHg**	Mean Arterial Pressure: _____ **mmHg**
Compliance: _____ **mm/mmHg**	Automated Pulse Pressure: _____ **mmHg**
Distensibility: _____ **%**	
Section 5 Continued: Left Ventricular Mass Measurements	
End Diastolic Volume: _____ **ml**	Stroke Volume: _____ **ml**
End Systolic Volume: _____ **ml**	LMVbsa: _____ **g/m^2**

Appendix D

Movement Assessment Battery for Children, Version 2



Movement Assessment Battery for Children – 2

Test Record Form Age Band 3 (11-16 years)

Name: Gender: M / F

Home address:

School: Class/year/grade:

Assessed by:

Referral source:

Preferred (writing) hand:

Movement ABC-2 Checklist completed? Y / N

	Year	Month	Day
Date tested			
Date of birth			
Chronological age			

Item Scores and Equivalent Standard Scores

Item code	Name of item	Raw score (best attempt)	Item Standard Score
MD 1*	Turning Pegs preferred hand		
	Turning Pegs non-pref hand		
MD 2	Triangle with Nuts and Bolts		
MD 3	Drawing Trail 3		
A&C 1	Catching with one Hand – best hand		
	Catching with one Hand – other hand		
A&C 2	Throwing at Wall Target		
Bal 1*	Two-Board Balance		
Bal 2	Walking Toe-to-Heel Backwards		
Bal 3	Zig-Zag Hopping best Leg		
	Zig-Zag Hopping other Leg		
Total Test Score Sum of 8 item **standard** scores			

*For Turning Pegs, Catching with One Hand and Zig Zag Hopping, look up standard score for each limb, add these and divide by 2.

Three Component Scores*

Manual Dexterity* MD 1 + MD 2 + MD 3		
Component score	Standard Score	Percentile

Aiming & Catching* A&C 1 + A&C 2		
Component score	Standard Score	Percentile

Balance* Bal 1 + Bal 2 + Bal 3		
Component score	Standard Score	Percentile

*In each case sum the item standard scores.

Total Test Score	Standard Score	Percentile Rank

Manual Dexterity 1: TURNING PEGS

Record: Preferred hand: R / L (should be same as for Drawing Trail); Time taken (secs); **F** for failure; **R** for refusal; **I** if inappropriate (note reasons below)

Preferred hand		Only administer a second trial if the first trial takes longer than the time stated below:							Non-preferred hand		Only administer a second trial if the first trial takes longer than the time stated below:						
Trial 1			11.0-11.11	12.0-12.11	13.0-13.11	14.0-14.11	15.0-15.11	16.0-16.11	Trial 1			11.0-11.11	12.0-12.11	13.0-13.11	14.0-14.11	15.0-15.11	16.0-16.11
Trial 2			35 secs	32 secs	32 secs	29 secs	29 secs	29 secs	Trial 2			31 secs	26 secs	26 secs	29 secs	29 secs	29 secs

Qualitative observations

Posture/body control

- Sitting posture is poor ☐
- Holds head too close to task ☐
- Holds head at an odd angle ☐
- Does not look while manipulating pegs ☐
- Does not use pincer grip to pick up pegs ☐
- Exaggerates finger movements in releasing pegs ☐
- Does not use the supporting hand to hold board steady ☐
- Does extremely poorly with one hand (asymmetry striking) ☐
- Changes hands or uses both hands during a trial ☐
- Hand movements are jerky ☐
- Moves constantly/fidgets ☐

Adjustment to task requirements

- Misaligns pegs with respect to holes ☐
- Uses excessive force when inserting pegs ☐
- Is exceptionally slow/does not change speed from trial to trial ☐
- Goes too fast for accuracy ☐
- **Other** _____

Comments: _____

Manual Dexterity 2: TRIANGLE WITH NUTS AND BOLTS

Record: Time taken (secs); **F** for failure; **R** for refusal; **I** if inappropriate (note reasons below)

No. of seconds		Only administer a second trial if the first trial takes longer than the time stated below:					
Trial 1			11.0-11.11	12.0-12.11	13.0-13.11	14.0-14.11	15.0-15.11	16.0-16.11
Trial 2			55 secs	48 secs	48 secs	48 secs	48 secs	48 secs

Qualitative observations

Posture/body control

- Sitting posture is poor ☐
- Holds materials too close to face ☐
- Holds head at an odd angle ☐
- Does not look at hole while inserting bolt ☐
- Does not use pincer grip to hold nuts and bolts ☐
- Finds it difficult to hold bolt with one hand and screw nut on with the other ☐
- Changes hands during a trial ☐
- Hand movements are jerky ☐
- Moves constantly/fidgets ☐

Adjustment to task requirements

- Sometimes misses hole with tip of bolt ☐
- Gets muddled in the construction sequence ☐
- Is exceptionally slow/does not change speed from trial to trial ☐
- Goes too fast for accuracy ☐
- **Other** _____

Comments: _____

Manual Dexterity 3: DRAWING TRAIL 3

Note: Bic Atlantis pen to be used

Record: Hand used: R/L/Both; No. of errors; F for failure; R for refusal; I if inappropriate (note reasons below)
Number of errors should be counted after testing using scoring criteria provided in Appendix A of the Manual.

	No. of errors
Trial 1	
Trial 2	

Do not administer a second trial if the child completes the first trial perfectly (i.e. no errors).

Qualitative observations

Posture/body control

- Sitting posture is poor ☐
- Holds head too near paper ☐
- Holds head at an odd angle ☐
- Does not look at trail ☐
- Holds pen with an odd/immature grip ☐
- Holds pen too far from point ☐
- Holds pen too close to point ☐
- Does not hold paper still ☐
- Changes hands during a trial ☐
- Moves constantly/fidgets ☐

Adjustment to task requirements

- Progresses in short jerky movements ☐
- Uses excessive force, presses very hard on paper ☐
- Is exceptionally slow ☐
- Goes too fast for accuracy ☐
- **Other** _____

Comments: _____

Aiming & Catching 1: CATCHING WITH ONE HAND

Record: Number of correctly executed catches; R for refusal; I if inappropriate (note reasons below)

Right Hand Practice: ☐☐☐☐☐ 10 Trials ☐☐☐☐☐☐☐☐☐☐ Total: _____

Left Hand Practice: ☐☐☐☐☐ 10 Trials ☐☐☐☐☐☐☐☐☐☐ Total: _____

Qualitative observations

Posture/body control

- Standing posture is poor ☐
- Does not follow trajectory of ball with eyes ☐
- Turns away or closes eyes as ball approaches ☐
- Holds hand out flat with fingers stiff as the ball rebounds ☐
- Hands and arms held wide apart, fingers extended ☐
- Arm and hand do not 'give' to meet impact of ball ☐
- Fingers close too early or too late ☐
- Does extremely poorly with one hand (asymmetry striking) ☐
- Movements lack fluency ☐

Adjustment to task requirements

- Does not adjust body position for catching ☐
- Does not adjust position of feet as necessary ☐
- Judges force of throw poorly (too much or too little) ☐
- Does not adjust to height of rebound ☐
- Does not adjust to direction of rebound ☐
- Does not adjust to force of rebound ☐
- **Other** _____

Aiming & Catching 2: THROWING AT WALL TARGET

Record: Hand used: R / L / Both; Number of successful hits; R for refusal; I if inappropriate (note reasons below)

Practice: ☐☐☐☐☐ 10 Trials: ☐☐☐☐☐☐☐☐☐☐ Total: _____

Qualitative observations

Posture/body control

- Balance while throwing is poor ☐
- Does not keep eyes on target ☐
- Does not follow through with the throwing arm ☐
- Releases ball too early or too late ☐
- Changes hands from trial to trial ☐
- Movements lack fluency ☐

Adjustment to task requirements

- Errors are consistently to one side of the target (asymmetry striking) ☐
- Control of direction is variable ☐
- Judges force of throw poorly (too much or too little) ☐
- Control of force is variable ☐
- Other _____

Comments: _____

Balance 1: TWO-BOARD BALANCE

Record: Time balanced (secs); R for refusal; I if inappropriate (note reasons below)

	No. of seconds
Trial 1	
Trial 2	

Do not administer a second trial if the child maintains balance for 30 seconds

Qualitative observations

Posture/body control

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐
- Sways wildly to try to maintain balance ☐
- Does not hold head and eyes steady ☐
- Makes no or few compensatory arm movements to help maintain balance ☐

- Exaggerated movements of arms and trunk disrupt balance ☐
- Cannot hold feet in a straight line ☐
- Other _____

Comments: _____

Balance 2: WALKING TOE-TO-HEEL BACKWARDS

Record: Number of correct consecutive steps from the beginning of the line; Whether entire line was walked successfully; R for refusal; I if inappropriate (note reasons below)

	No. of steps	Entire line?
Trial 1		YES / NO
Trial 2		YES / NO

Do not administer a second trial if the child completes 15 steps OR completes the whole line in fewer than 15 correctly executed steps

Qualitative observations

Posture/body control

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐
- Sways wildly to try to maintain balance ☐
- Does not look behind to check position on track ☐
- Does not compensate with arms to maintain balance ☐
- Exaggerated arm movements disrupt balance ☐
- Is very wobbly when placing feet on line ☐

Adjustments to task requirements

- Goes too fast for accuracy ☐
- Individual movements lack smoothness and fluency ☐
- Sequencing of steps is not smooth/pauses frequently ☐
- **Other** _____

Comments: _____

Balance 3: ZIG-ZAG HOPPING

Record: Number of correct consecutive hops (maximum of 5); R for refusal; I if inappropriate (note reasons below)

		No. of hops			No. of hops
Right Leg	Trial 1		Left Leg	Trial 1	
	Trial 2			Trial 2	

Do not administer a second trial if the child completes 5 perfect hops on the first trial

Qualitative observations

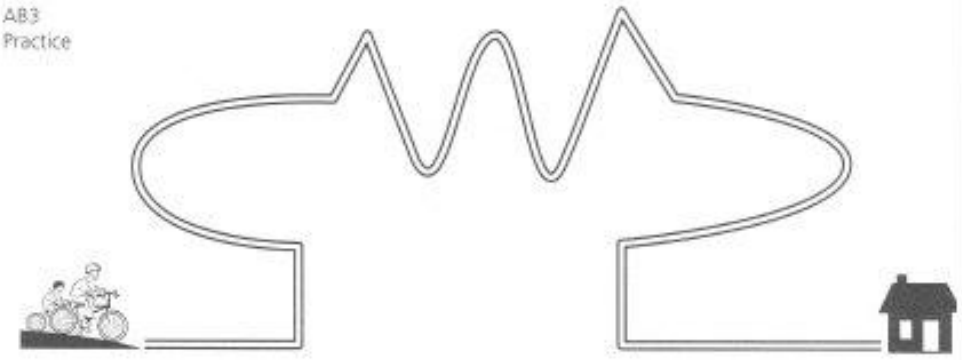
Posture/body control

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐
- Non-supporting leg held up in front of body ☐
- Hops with stiff legs/on flat feet ☐
- Lacks springiness/no push-off from feet ☐
- Arm movements are exaggerated ☐
- Does not use arms to assist hop ☐
- Stumbles on landing ☐
- Does extremely poorly with one leg (asymmetry striking) ☐

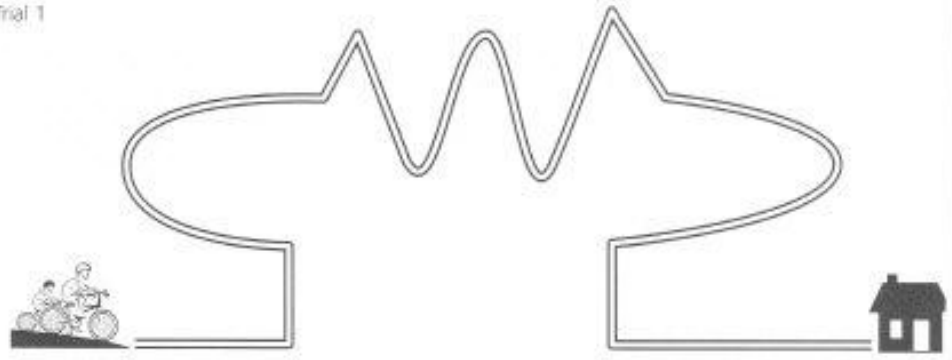
Adjustments to task requirements

- Goes too fast for accuracy ☐
- Does not combine upward and forward movements effectively ☐
- Uses too much effort ☐
- Movements are jerky ☐
- **Other** _____

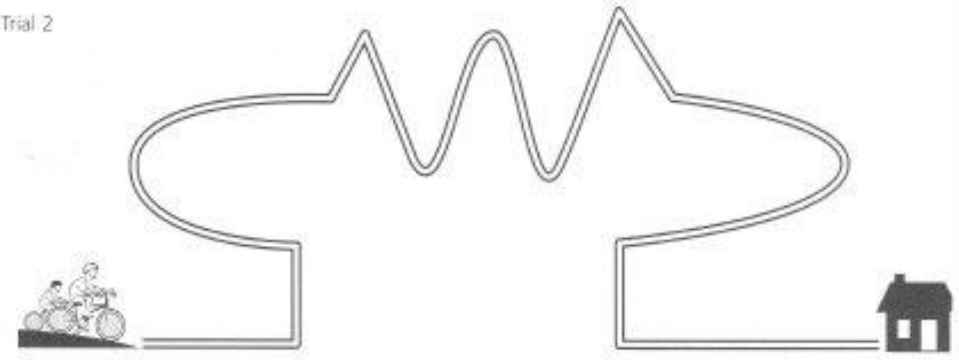
AB3
Practice



Trial 1



Trial 2



NON-MOTOR FACTORS THAT MIGHT AFFECT MOVEMENT

Complete the sections below by noting any features of the child's behaviour during testing that you suspect might have affected his or her motor performance. Headings (with examples) are given as guidelines only. Although negative aspects are given more emphasis, remember to note positive aspects of the child's behaviour.

	Yes	No
1. **Disorganised** (e.g. scattered clothes slows up dressing after PE; puts on shoes before socks).		
2. **Hesitant/forgetful** (e.g. slow to start complex actions; forgets what to do in the middle of an action sequence).		
3. **Passive** (e.g. hard to interest; requires much encouragement to participate).		
4. **Timid** (e.g. fearful of activities such as jumping/climbing; constantly asks for assistance).		
5. **Anxious** (e.g. trembles; becomes flustered in a stressful situation).		
6. **Impulsive** (e.g. starts before instructions are complete; impatient of detail).		
7. **Distractible** (e.g. looks around, responds to irrelevant noises).		
8. **Overactive** (e.g. squirms and fidgets; moves constantly when listening to instructions, fiddles with clothes).		
9. **Overestimates own ability** (e.g. tries to make tasks more difficult; tries to do things too fast).		
10. **Underestimates own ability** (e.g. complains of task difficulty; anticipates failure before starting).		
11. **Lacks persistence** (e.g. gives up quickly; is easily frustrated).		
12. **Upset by failure** (e.g. looks tearful; refuses to try task again).		
13. **Unable to get pleasure from success** (e.g. fails to respond to praise).		
Other (please specify).		
Overall, do you think these problems prevent the child from demonstrating his or her true movement capability (please circle)	not at all a little a great deal	

PHYSICAL FACTORS THAT MIGHT AFFECT MOVEMENT

Anatomical/postural defect: YES/NO Specify, if possible	
Vision defect: YES/NO	**Hearing defect:** YES / NO
Judgement of weight: average/overweight/underweight	
Judgement of height: average/tall/short	
Other	

Table 2a: Brief summary of changes made to AB1 – now covers ages 3 to 6 years

Task	Movement ABC AB1	Movement ABC-2 AB1
Manual Dexterity 1	Posting Coins	Posting Coins
Manual Dexterity 2	Threading Beads	Threading Beads
Manual Dexterity 3	Bicycle Trail	Drawing Trail 1*
Aiming & Catching 1	Catching Beanbag	Catching Beanbag
Aiming & Catching 2	Rolling Ball into Goal	Throwing Beanbag onto Mat**
Balance 1	One-Leg Balance	One-Leg Balance
Balance 2	Walking Heels Raised	Walking Heels Raised
Balance 3	Jumping over Cord	Jumping on Mats**

* Altered item: shape of trail has changed

** New item

Table 2b: Brief summary of changes made to AB2 and AB3 – now labelled AB2 and covers ages 7 to 10 years

Task	Movement ABC AB2	Movement ABC AB3	Movement ABC-2 AB2
Manual Dexterity 1	Placing Pegs	Shifting Pegs by Rows	Placing Pegs~
Manual Dexterity 2	Threading Lace	Threading Nuts on Bolt	Threading Lace^
Manual Dexterity 3	Flower Trail	Flower Trail	Drawing Trail 2*
Aiming & Catching 1	Two-Hand Catch	One-Hand Bounce and Catch	Catching with Two Hands
Aiming & Catching 2	Throwing Beanbag into Box	Throwing Beanbag into Box	Throwing Beanbag onto Mat**
Balance 1	Stork Balance	One-Board Balance	One-Board Balance
Balance 2	Heel-to-Toe Walking	Ball Balance	Walking Heel-to-Toe Forwards
Balance 3	Jumping in Squares	Hopping in Squares	Hopping on Mats+

Altered items:

~ New start position/layout

^ Lacing board now longer

* Shape of trail has changed

** Mat with target now used instead of box

\+ Mats used for this task

Table 2c: Brief summary of changes made to AB4 – now labelled AB3, covering ages 11 to 16

Task	Movement ABC	Movement ABC-2
Manual Dexterity 1	Turning Pegs	Turning Pegs
Manual Dexterity 2	Cutting-Out Elephant	Triangle with Nuts and Bolts^
Manual Dexterity 3	Flower Trail	Drawing Trail 3*
Aiming & Catching 1	One-Hand Catch	Catching with One Hand
Aiming & Catching 2	Throwing at Wall Target	Throwing at Wall Target
Balance 1	Two-Board Balance	Two-Board Balance
Balance 2	Walking Backwards	Walking Toe-to Heel Backwards
Balance 3	Jumping and Clapping	Zig-Zag Hopping^

^ New items

* Altered item: Shape of trail has changed

Appendix E

Tanner Staging Pictures

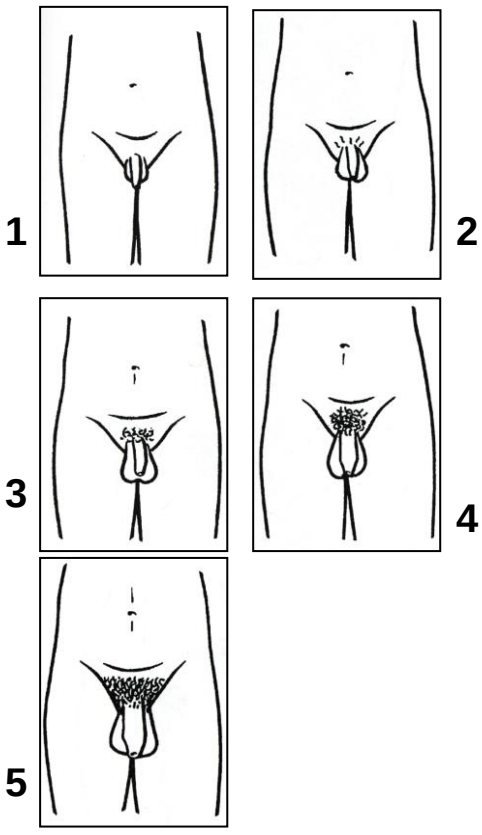
Male Pubertal Stage

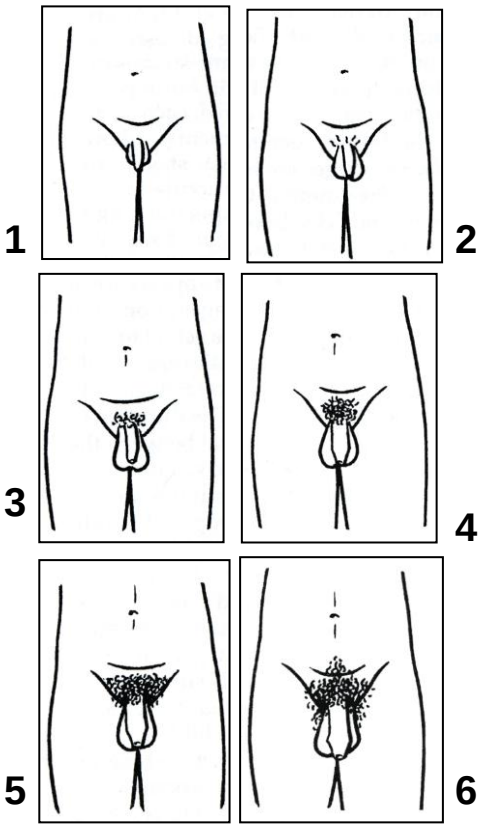
FACULTY OF APPLIED HEALTH SCIENCES

BROCK UNIVERSITY

This survey will be used to assess the maturational levels of the participant. For each photo choose the appropriate stage and place an X in the corresponding square.

- Please circle the box that looks most like you
- Please look at the penis size only
- Please look at the pubic hair only
- Please circle the box that looks most like you





Female Pubertal Stage

BROCK UNIVERSITY

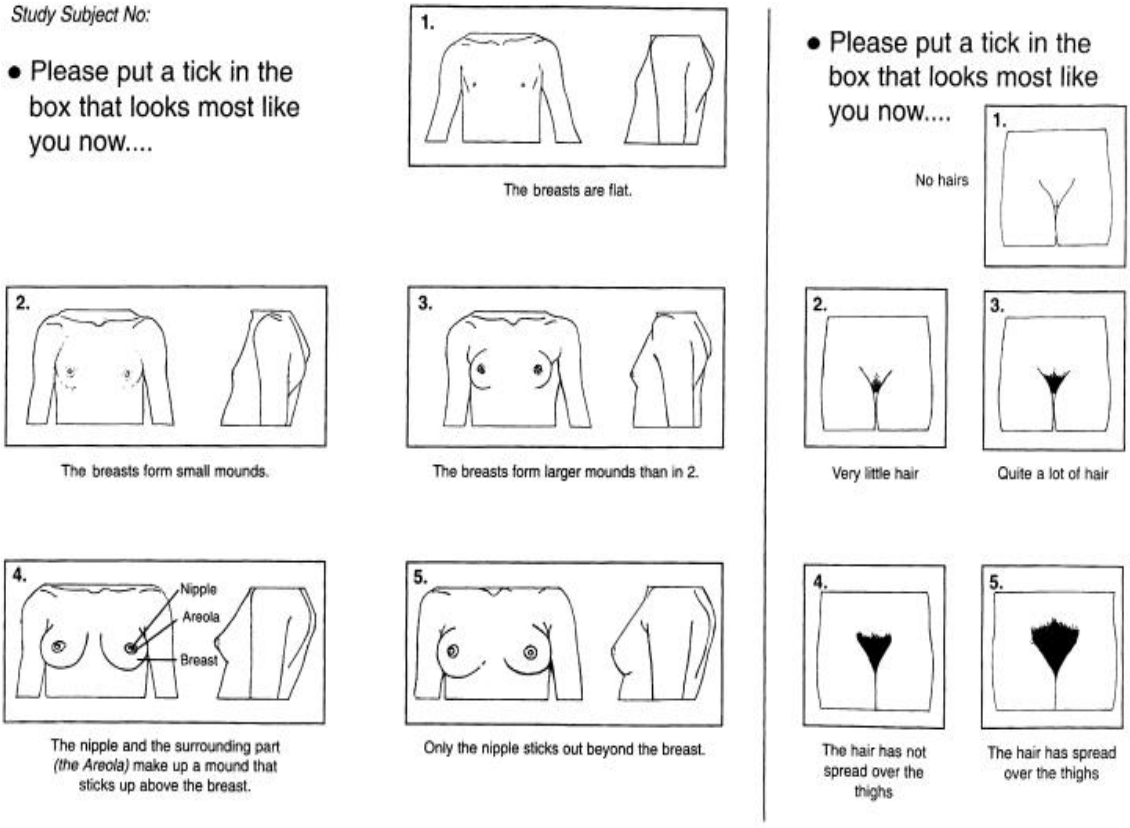
FACULTY OF APPLIED HEALTH SCIENCES

This survey will be used to assess the maturational levels of the participant. For each photo choose the appropriate stage and place an X in the corresponding square.

Directions: You should choose only one of the stages shown below. One stage for Breast development and one stage for Pubic Hair development.

Study Subject No:

- Please put a tick in the box that looks most like you now....



- Please put a tick in the box that looks most like you now....

Please answer the following questions:

1. Have you had your period? YES NO
2. How old were you when you had your first period? _____
3. How often do you get periods? (in days)_____